SEWAGE AND INDUSTRIAL WASTES

(Formerly Sewage Works Journal)

JOURNAL of the FEDERATION OF SEWAGE AND INDUSTRIAL WASTES ASSOCIATIONS

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Radioactive ABS in Activated Sludge—House and Fries

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APRIL, 1956—VOL. 28, No. 4

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OF THE

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IN CONJUNCTION WITH

CALIFORNIA SEWAGE AND INDUSTRIAL WASTES ASSOCIATION

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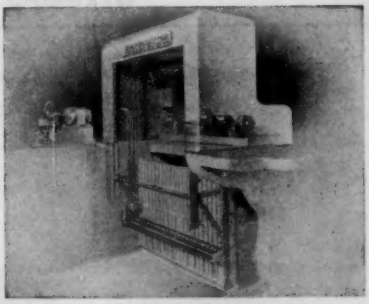

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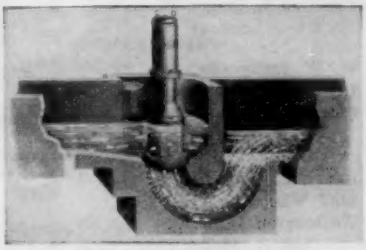

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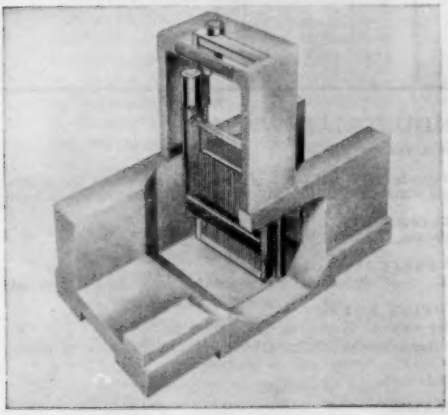

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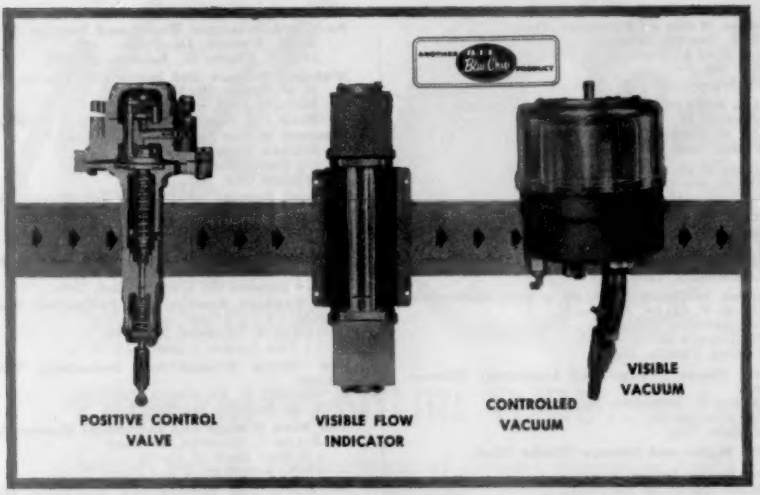

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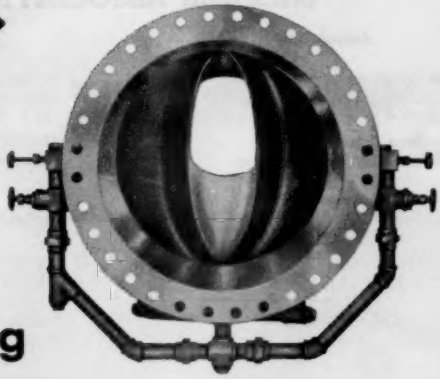

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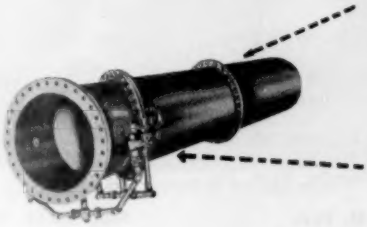

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Association	*Place*	*Time*
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Arizona Sewage and Industrial Wastes Assn.	Buena Vista Hotel Safford, Arizona	Apr. 5–7, 1956
Virginia Industrial Wastes and Sewage Works Assn.	Natural Bridge Hotel Natural Bridge, Va.	Apr. 19–20, 1956
California Sewage and Industrial Wastes Assn.	Santa Rosa Hotel Santa Rosa, Calif.	Apr. 25–28, 1956
Maryland-Delaware Water and Sewage Assn.	Willard Hotel Washington, D. C.	May 10–11, 1956
Michigan Sewage and Industrial Wastes Assn.	Whitcomb Hotel St. Joseph, Mich.	May 14–16, 1956
Alabama Water and Sewage Assn.	Alabama Polytechnic Auburn, Ala.	June 4–6, 1956
Föreningen För Vattenhygien	Karlstad, Sweden	June 7–8, 1956
Ohio Sewage and Industrial Wastes Treatment Conference	Hotel Carter Cleveland, Ohio	June 13–15, 1956
Institute of Sewage Purification	Harrogate, England	June 18–22, 1956
Central States Sewage and Industrial Wastes Assn.	Northland Hotel Green Bay, Wis.	June 20–22, 1956
Pennsylvania Sewage and Industrial Wastes Assn.	Pennsylvania State University University Park, Pa.	Aug. 29–31, 1956
Iowa Sewage and Industrial Wastes Assn.	P. M. Park Clear Lake, Iowa	Sept. 12–14, 1956
Kentucky-Tennessee Industrial Wastes and Sewage Works Assn.	Hotel Patten Chattanooga, Tenn.	Sept. 17–19, 1956
Georgia Water and Sewage Assn.	Hightower Textile Bldg. Georgia Inst. of Technology, Atlanta, Ga.	Sept. 19–21, 1956

TWENTY-NINTH ANNUAL MEETING

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October 8–11, 1956

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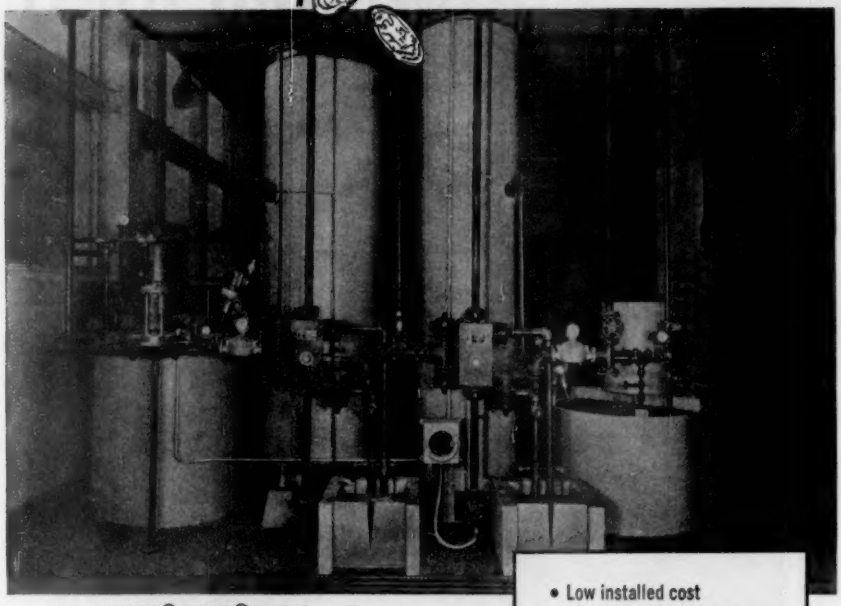

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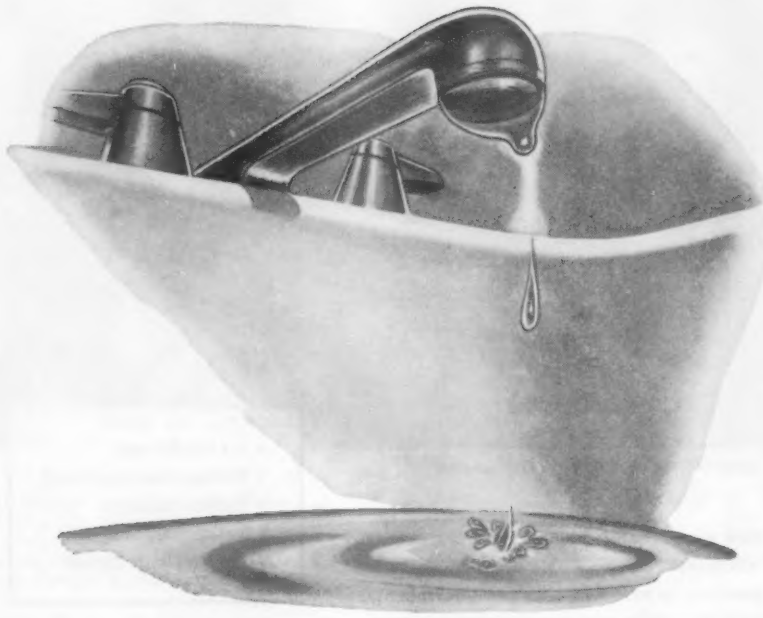

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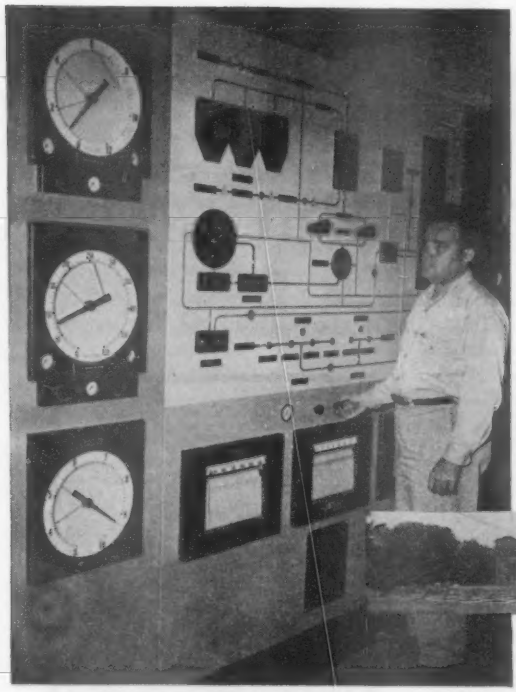

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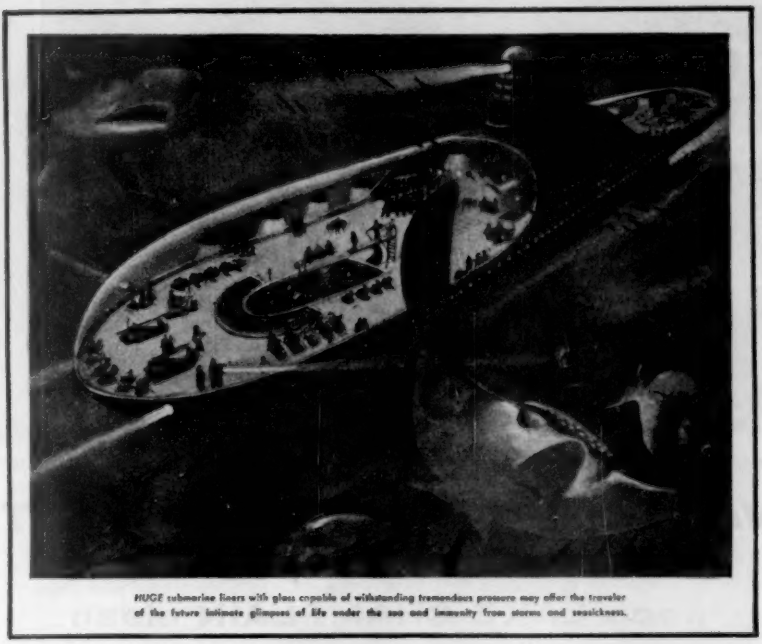

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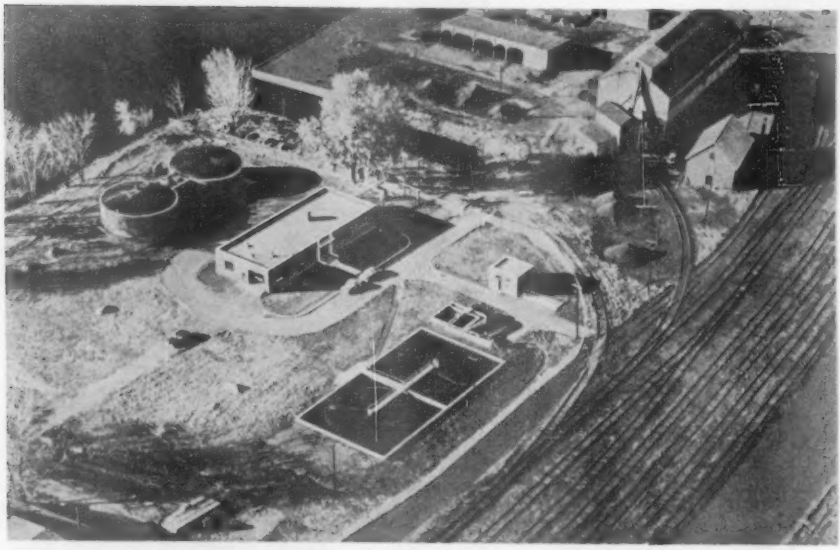

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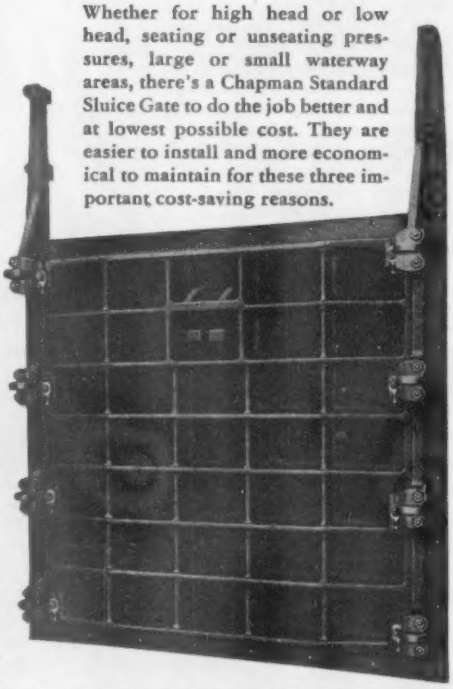

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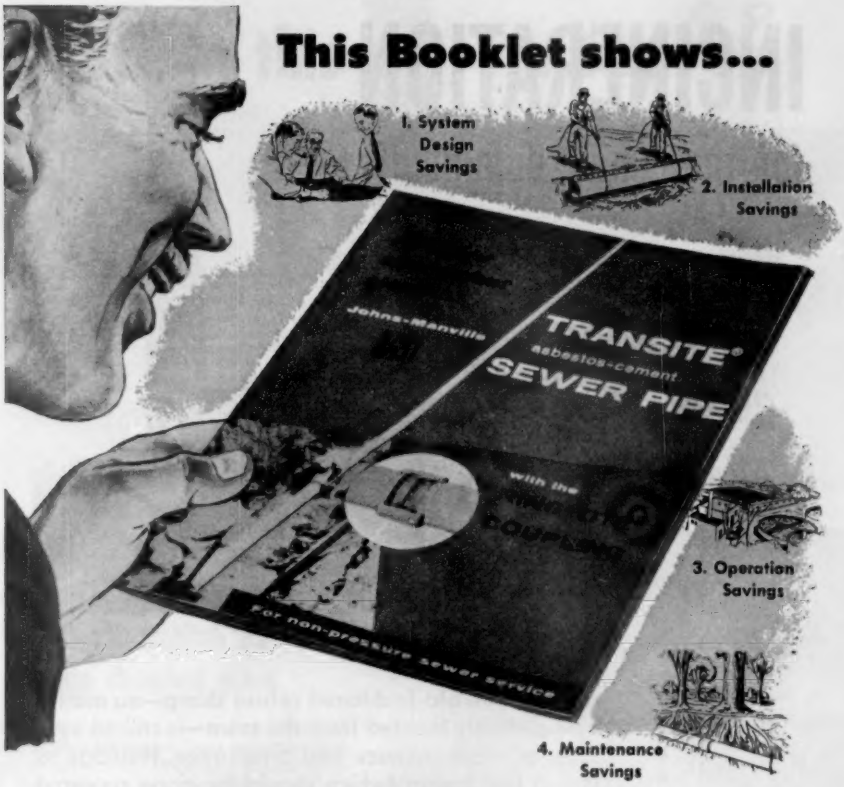

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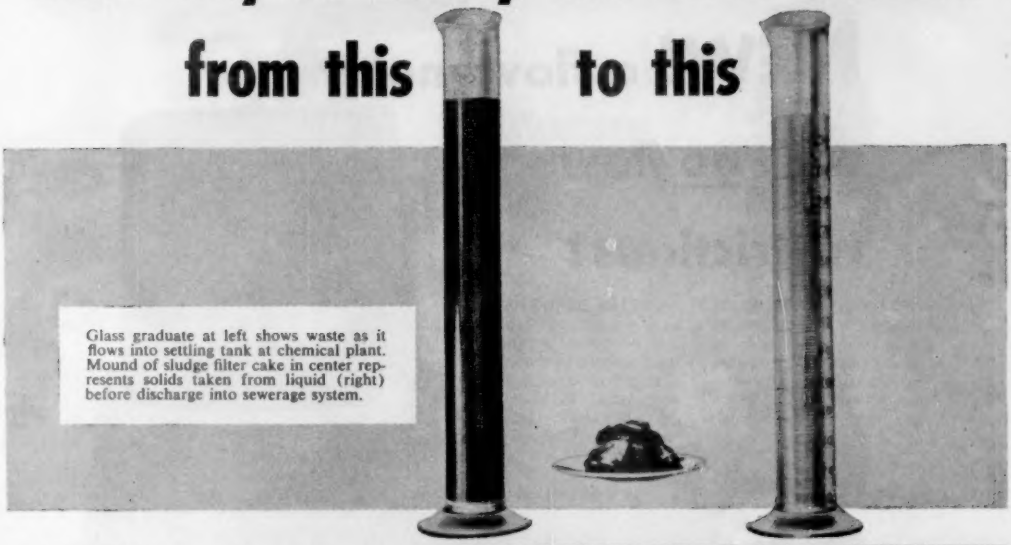

Glass graduate at left shows waste as it flows into settling tank at chemical plant. Mound of sludge filter cake in center represents solids taken from liquid (right) before discharge into sewerage system.

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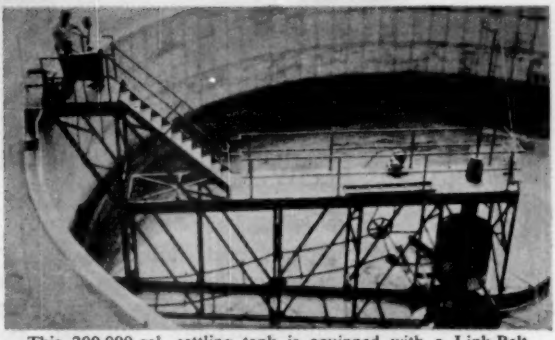

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SEWAGE AND INDUSTRIAL WASTES

Journal of the Federation of Sewage and Industrial Wastes Associations

Volume 28 **April, 1956** **Number 4**

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Aerial view of the Ada plant taken in 1954 shortly after starting up. Clariflocculator unit at left. Consulting Engineer: Ralph W. Delaney, Ada, Oklahoma.

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Sewage Works

FRINGE-AREA SANITATION—A SYMPOSIUM *

I. NATIONAL PROBLEM

By John E. Kiker, Jr.

Professor of Civil Engineering, University of Florida, Gainesville, Fla.

In recent years there has been a mass exodus of population to the fringe areas surrounding parent cities. For economic and other reasons the extension of public sewerage and water supplies has not kept pace with the relocation of population. The problem of furnishing these facilities is most perplexing in some instances, and almost every state is having trouble with fringe-area sanitation programs.

In some areas the problem of obtaining adequate water supplies has been difficult to solve. People are not as likely to locate where there is an inadequate water supply as they are where there is no sewer system. Accordingly, the provision of satisfactory sewerage facilities poses the most difficult problem in a majority of cases. Often septic tank systems are allowed in non-sewered areas where soil conditions are unsuitable and building lots are too small. As a result, many public health nuisances are created and much time, money and comfort are lost through lack of foresight and failure to apply basic engineering principles in the selection, layout, design and construction of the sewage disposal facilities.

Considering the number of failures of septic tank systems, it may seem surprising that the problem has not been more widely recognized and properly attacked. In the past, however, a great many engineers have considered it beneath their dignity to become associated with the problem. This very fact is believed to be one of the reasons for the present state of affairs. It simply must be recognized that some real engineering is needed for the proper solution of the fringe-area problems.

The situation and attendant problems have been receiving increased attention from state and Federal health officials. For several years now the U. S. Public Health Service has engaged in research on septic tanks and related problems. Several reports have been prepared and at present work is progressing on a new manual of septic tank practice. In addition, a special committee of the American Society of Civil Engineers is presently studying fringe-area sanitation problems.

General observations indicate that the problems of fringe-area sanitation are just as acute in California as in Florida, Kansas or New Jersey. The problems in most areas are similar, and the basic tenets involved in their solution are also similar to a considerable degree.

* Presented at 28th Annual Meeting, Federation of Sewage and Industrial Wastes Assns.; Atlantic City, N. J.; Oct. 10–13, 1955.

II. FRINGE-AREA SANITATION IN NEW JERSEY

By I. Russell Riker

Sanitary Engineer, Princeton Borough and Township, and Princeton University, Princeton, N. J.

The present trend of population movement from town and city to the country has affected New Jersey in the same way as other parts of the United States. As a result, a serious sanitary problem has been created in the fringe area, including the area within the boundary of the municipality as well as that adjacent thereto. The growth of population has been remarkable. The townships surrounding small populated boroughs have increased in population beyond that of the boroughs. There are in New Jersey, a comparatively small state, more than 500 municipal corporations, the mapority of which have small populations with part-time municipal employees. As a result, the municipalities have been unable to cope with the sanitary problems of water, sewage, drainage and garbage disposal. The most serious problem is that of providing adequate sewerage facilities.

Developers of housing have naturally been trying to keep the cost of their developments to a minimum and they have made every effort possible to get financial help from towns and cities when the developments were within corporate limits. Fortunately, officials soon realized it was unfair to the existing taxpayers to provide new trunk sewers, water mains, schools and other utilities for this new population growth, which in some cases did not provide enough in taxes to meet the new expenses made necessary by the extensions. Developers frequently subdivided farms with little municipal control. In many of the townships there was no sewer system and in some, no water supply, municipal collection of garbage or storm drains.

As a result of this lack of sanitary facilities, planning laws for the regulation of subdivisions have been revised and strengthened. Standards developed by a committee appointed by the governor of New Jersey, were written into the planning laws. At present land cannot be subdivided unless it meets the planning law standards, nor can a building permit be issued unless the building is to be located on an improved municipal street. The local board of health must certify that the soil at the building site is suitable for an individual sewage disposal system, if an approved sewer system is not available.

The expense of extending the water mains and increasing the main sizes to reach the suburbs has caused developers and even individuals to install their own water systems. A similar situation applies when sewers are either of inadequate capacity or the cost of long connecting trunk lines would be uneconomical. These conditions have developed gradually since about 1946, until it became obvious that acute unsanitary conditions not only were occurring, but were under very little official control.

One of the first steps undertaken by the planning board was to require larger building lots where individual sewage disposal systems were necessary. It had not been uncommon to find subdivisions where individual cesspools and/or septic tanks were constructed on lots as narrow as 50 ft., and with a depth of only 100 to 150 ft. In one particular case, where the first part of the development was on high ground and the cesspools worked fairly well, a portion of the subdivision was on lower ground with the water table near the surface; the entire area soon became a health menace. Sewage overflowed on the surface of the ground, the septic tank effluent broke through the sub-surface irriga-

tion system and ran down the gutters in the streets or collected in the depressed areas in the center of the block. In this case a sewer system to serve 150 families was the only solution. This finally was done after several court cases and much negotiation. The individual home owners ultimately paid double and, in addition to the cost of the original system, they are now charged an annual sewer rental which includes the capital and operating cost of this new municipal system.

Legislation

The New Jersey State Department of Health, realizing the seriousness of the problem, was instrumental in proposing effective legislation for the control of unsanitary conditions. Appropriate legislation was enacted in 1954 to control sanitation in realty subdivisions and individual dwellings.

Briefly, the New Jersey law provides that no building permit for the construction of a realty improvement shall be issued by any municipal authority until the board of health having jurisdiction shall have certified that the proposed water supply system and sewage facilities are in compliance with the provisions of the law. Provision is made for the submission of a formal application, accompanied by engineering data, for certification by the local board of health.

In developments of 50 or more houses, copies of the applications and data also are filed with the state department of health. The state health department may revoke any certification provided that such action is taken within 15 days of filing. Penalties are provided for violation of any of the provisions of the act. The use of professional engineers by local boards of health in dealing with this problem is written into the law. The local board of health may accept the certification of a professional engineer, provided the application and accompanying engineering data are in compliance with the act and the standards for construction.

Standards

In compliance with the provisions of the law, the state health commissioner appointed a committee to develop suitable standards for subdivision developments. The standards committee is composed of representatives from the Association of Real Estate Boards, the Health Officers Association, the Society of Professional Engineers, the League of Municipalities, the Home Builders Association, the Institute of Municipal Attorneys, the Title Insurance Association and one each from the State Department of Conservation and Economic Development, and the State Department of Health.

Standards for individual sewage disposal systems were agreed upon and officially adopted after nearly two years of study. Paragraph 2.11, General Requirements, entitled "Discharge of Effluents" is of particular interest. "Individual sewage disposal systems shall not be designed, constructed or located in a manner that will permit the discharge of an effluent onto the surface of the ground or into any watercourse." The standards cover such specific items as building sewers, septic tanks and various methods of final disposal. Particular attention is given to soil characteristics and percolation tests. It is expected that these standards will aid the local health department official and provide the builder and developer with a positive guide of what is expected in the way of sanitary facilities. Ultimately the fringe-area resident and his family benefit through a healthier environment and sustained property values.

Acknowledgment

Appreciation is expressed to Alfred H. Fletcher, Director, Bureau of Environmental Sanitation, New Jersey State Department of Health, for his assistance.

III. SEWER DISTRICTS IN SUBURBAN DEVELOPMENT

By Myron K. Nelson and Dwight F. Metzler

Respectively, Chief Engineer, Mission Township Sewer District Mission, Kans., and Chief Engineer, Kansas State Board of Health, Lawrence, Kans.

This paper presents some general engineering and financial considerations for organizing sewer districts and providing sewerage service in metropolitan fringe areas. Since the authors are directly concerned in and familiar with the problems in Kansas, this paper will deal largely with Kansas areas which abut and are adjacent to Kansas City, Kans. and Kansas City, Mo.

Area Characteristics

The population of northeast Johnson County, Kans. has grown from 12,000 persons in 1945 to 85,000 persons in 1955 and a similar, though not as marked, increase has occurred in adjacent Wyandotte County. Some leveling off in the rate of growth has occurred recently, principally for lack of adequate public sewerage facilities for a large part of the area. In 1945 the area was largely rural and was governed by the boards of county commissioners. At that time all public improvements had to be authorized by special acts of the Kansas Legislature. As the area developed from a rural to a suburban area, growing pains were apparent but no satisfactory remedies were forthcoming under the governmental laws which were designed primarily to fit a farming community. Several small communities incorporated as third class cities and at present there are 12 incorporated cities and an incorporated urban township government in northeast Johnson County. Boundaries of the cities and the urban township coincide. The problems of the cities are almost identical but minor differences and local pride have kept the communities from merging into one major city. The largest city in the metropolitan area has a population of 15,000 people and the smallest about 250. Each city has its own zoning board while the urban township zoning board is under the jurisdiction of the board of county commissioners. Several unsuccessful attempts have been made to organize a single, over-all planning board.

Sewage Disposal Problems

The problems of disposing of sewage have afflicted this general area for 20 years. Soil conditions generally are not conducive to the satisfactory performance of either septic tanks or cesspools. Several small community-type sewage treatment plants were used by developers when the populated areas were widely scattered. These plants were generally of the septic tank-sand filter type. One contact aeration facility functioned very satisfactorily until grossly overloaded. Inadequate operation, overloading of treatment plants, dry receiving streams, and growing density of population adjacent to the treatment plants brought on problems of stream pollution, odors and health.

In other parts of the area, individual septic tanks were constructed. As the population density increased and septic tanks failed, complaints to the local and state health departments became numerous. Unfortunately, there was no agency, either state or local, with the authority to prohibit the building of sewerage systems on individual lots in places where failure was a foregone conclusion. Septic tanks, with sewage seeping or flowing to the surface of the ground, could be condemned by the public health authorities but lack of any other means

of sewage disposal was a severe handicap. Fines could be assessed against offending parties, but small lots and impervious soil prevented any effective solution to the problem.

When it became apparent that further development of the area was being retarded, developers and owners of large tracts of land became alarmed and made a concerted effort to get the special legislation needed to create a public sewer district. Such a law was enacted by the 1945 session of the Kansas Legislature. Subsequently a sewer district was organized and bonds were voted. The election was carried by a big majority although only a small percentage of qualified electors voted.

Public Districts and Methods of Organization

General Considerations

Several important factors should be considered in setting the boundaries of any sewer district. The first is topography. Where possible, an entire drainage area should be included in a district. If more than one drainage area is to be included, the economics of duplicate sewage treatment plants versus larger collecting sewers and pumping to a central treatment plant must be considered. Prospective uses of land may influence district boundaries or the type of district. In many areas property owners of large tracts suitable for development may have varied and conflicting interests with respect to use of the land. The gentleman farmer group may want the countryside to remain in grass to feed a few head of cattle. Dirt farmers usually find that their land is more valuable for homesites than for farming. These two types of owners, together with persons owning homes in any existing developed area, make up the property owners in the usual proposed sewer district. With such a heterogeneous group, thrown together by geographical accident but with widely varied interests, it is not surprising that a sewer district may have to defer major capital expenditures because of financing limitations. In Kansas the revenue bond provisions are generally applicable to cities, but sewer districts outside of cities usually have to rely on general obligation bonds for financing sewers and sewage treatment.

County Districts

Several types of sewer districts can be organized. The first is the county district which can be formed by action of the county commissioners without petition from the property owners. The creation of this type of district requires only the formal resolution of the county court or county commissioners whenever a suitable boundary is described. The governing body may hire professional engineers to make a preliminary report and cost estimate. However, a bond election must be held and the approval of the voters obtained before money is available for construction. Should the election fail, all expenses for the preliminary report and election may be paid by a single levy on all real property within the boundaries of the district. This plan has the advantage of permitting considerable advance planning and is well suited to areas where development is scattered.

Township District

The township board in any township having a water supply is authorized to create a sewer district by resolution after giving proper notice. Property owners may protest and, if those owning more than one-half the land in the area do so within 20 days, the district may not be created. After formation of the district, the township board acts as the governing body and is authorized to employ engineers for planning. Costs for the preparation of plans are paid by an assessment against the property in the district.

Financing of construction must be approved at a special bond election.

Main Sewer District

A third type of sewer district may be formed by resolution of the county commissioners upon receipt of a petition signed by the owners of more than 10 per cent of the area. This is called a "main sewer district" and it provides trunk sewers and treatment facilities only. The original boundary may be tentative and may be changed at a later date by written requests of property owners at a formal hearing. Upon receipt of such a petition the county commissioners may hire engineers to make preliminary studies, reports and cost estimates. A favorable election is required before detailed plans and specifications may be prepared for construction of the sewerage facilities. If the election is not favorable all expenses of the project may be paid by issuance of no-fund warrants to be paid by a levy against real property within the district.

Variant Methods

A slightly different method of creating a main sewer district can also be used. A petition may be presented, signed by more than 500 qualified electors residing within the proposed district. This method is laborious and is impossible of achievement in some areas. The first method is adapted to areas with scattered population and is usually initiated by developers. The second plan is suited to more densely populated areas. It cannot be initiated by developers without the support of local owners and residents. Financing is accomplished by issuing general obligation bonds of the district. Lateral districts are created by petition of the owners of more than 50 per cent of the land within the proposed lateral district. These sewers are financed by main sewer district bonds.

Another type of county sewer district can be organized by resolution of the county governing body. It requires a petition signed by the owners of more than 51 per cent of the area. The county commissioners can create it upon receipt of the petition and proceed to hire professional engineers, sell bonds without an election, and construct the sewers. The bonds are county obligations which pledge the credit of the entire county and, because they are general obligation bonds, are easily marketed at a favorable rate of interest. This type of district is suitable for the larger builders who develop an entire area. It is adapted to a smaller area than the district requiring a bond election to finance. The statute authorizing this district is based on the presumption that all sewers and treatment facilities will be constructed by the district as a whole.

Private Construction and Ownership

Districts privately owned and constructed have several distinct advantages and some disadvantages. The principal advantage lies in the fact that sewerage facilities may be provided without public financing. If properly arranged, a complete sewer system can be developed free of bonded debt. Such a plan eliminates the need for septic tanks or other temporary facilities and earlier development of an area can be accomplished. With proper planning the initial system can be an integral part of an over-all system to be developed at a later date. The principal disadvantage of this plan is the limited area that one developer may control. If no over-all planning or control can be accomplished, several small districts may emerge without adequate means to maintain their systems. Furthermore, when the developer sells his property there is usually no responsible party to take over the operation of the facilities. Two methods have

been used to insure proper maintenance.

Private Operation

Home Owners' Association

Under the first method of private operation a home owners' association is organized and endowed with the power to levy and collect a maintenance fee on a monthly or other basis. The association is empowered with the authority to hire the necessary personnel to operate the system. One drawback to this method has been a general reluctance on the part of property owners to pay the necessary fees. While the failure to pay a fee may result in a lien on the property, officials in the association are usually unwilling to take action against their neighbors. Experience has also revealed an almost complete lack of interest in the system by home owners. Only those persons living nearest to the treatment plant, or those directly concerned by its failure, take any active interest. It is doubtful whether a public health agency could take any effective legal action against such an association. Some attorneys have offered the opinion that any action would have to be taken against the owners individually. For these reasons nearly all privately constructed small systems in the Kansas City area have been taken over by sewer districts which have been formed under the responsible charge of public officials and maintenance charges have been collected as a tax. The maintenance and operation costs of these small systems are relatively high.

Nonprofit Sewer Corporations

The second method for insuring proper operation and maintenance of privately constructed systems has been through the organization of a nonprofit sewer corporation. Each lot owner is automatically a stockholder in the corporation. The most important advantage of this method over the first is that the corporation is a legal entity which can be forced to maintain the system. Otherwise the same disadvantages occur under this method as under the method previously discussed.

Final Integration

The most serious disadvantage of private ownership and operation of a sewerage system as a utility, however, is the difficulty of finally integrating such systems into one over-all system. For example, one large private system near Kansas City, Mo. has been functioning satisfactorily for some time. As the system was enlarged, contracts for sewer service were entered into with other developers and with individual owners in the original system. The original developer has now completed the development of the major part of the area tributary to the sewer system and is desirous of turning the system over to a public body. However, since part of the system is within the boundaries of an incorporated city and the remainder outside, the system cannot become a city system without legislative action. And, because of the hundreds of individual contracts with home owners, the existing laws will probably have to be modified before a public district can be created. Total development of the sewered area will result in at least a theoretical overload on the system. Because of the contracts in force, enlargement of the facilities under a public district probably cannot be charged against the district as a whole but only against the vacant land. This charge would, in all probability, be confiscatory. In the sales contract of each home purchaser is a clause permitting the original developer to give the system to the property owners. They must accept it even though there is no organization or official body to maintain it. Even this, however, is preferable to the oc-

casional practice of charging the costs of the sewerage system against the individual lots and later selling the system to the home owners, which constitutes a double charge.

Methods of Encouragement

Role of Local Health Department

The local health department plays an important role in the development of large sewer districts. Unfortunately large sewer districts cannot be created and developed simply because public health authorities can see a need for them. Developers of land are frequently interested only in making as much profit as possible and, in some cases, they build as cheaply as the governing agencies will permit. It is a responsibility of the health authorities to see that economies should not include substandard sewerage facilities.

The local health departments usually discourage the construction of septic tanks in areas not suited for their use. The use of septic tanks must be approved by a health authority and proper inspections made before a Federal Housing Administration or Veterans Administration guaranteed loan may be granted for new construction. In the case of large developments the local health department, in the absence of political interference, can guide the developers into the use of adequate sewer systems by refusing to approve individual septic tanks. This procedure must be carried out objectively and fairly so that private individuals are not deprived of their rights. If septic tanks are installed without the advice of health authorities, public nuisances and health hazards are sure to develop and there will be no adequate means to eliminate them. Developers of land, when required to do so, can usually find a way to construct adequate facilities.

A second function of the local health department in encouraging large sewer districts is to enforce strictly the laws prohibiting the discharge of sewage to ditches. The cooperation of the city or county attorney is required if this objective is to be accomplished effectively. This is an unpleasant duty in most cases but it is extremely vital.

A third function of the local health department is to keep the issue of proper sewage disposal constantly before the public. If it is brought to their attention often enough, home owners will be aware of the problem and will demand proper facilities. This was demonstrated by an experience in 1948. Individual septic tanks in new housing developments were failing rapidly but neither the state laws nor local ordinances were adequate to prevent the building of more houses with septic tanks which would also fail. The Kansas State Board of Health called a public meeting to discuss the problem. Testimony was received from builders and home owners. The publicity which resulted from this meeting literally stopped the buying of houses served with septic tanks for several months.

The health department can also assist in the development of large sewer districts by collecting and disseminating data on soil characteristics and septic tank performance in the area. Data on the cost of construction and maintenance of septic tanks should also be obtained. The facts will show that a large sewerage system is a sounder investment to the home owner than a septic tank system.

Functions of a Planning Board

The planning board, properly informed on the merits of a large sewer district versus individual septic tanks, can be a very important influence. The planning board can require proper sewerage facilities before property is zoned for housing, industry or retail business. If the full cooperation of the health authorities is obtained, restrictions will be placed on

the use of land until sewerage facilities are available.

A second important function of the local planning board is the reservation of easements for sewers and other utilities in the acceptance of plats. This permits orderly and economical development of the utilities, including sewers.

Administrative Action

Local and state agencies can encourage the development of large sewer districts through administrative action such as requiring provision for adequate sewerage facilities before building permits are granted. These agencies can encourage over-all planning with a minimum area laid out as acceptable for the development of a permanent sewer system. By agreement between owners, smaller districts can be created initially which will later become parts of the larger permanent district. Such a plan has been followed in Johnson County with considerable success.

Temporary Facilities

Temporary sewage treatment facilities under public control have been approved by the Kansas State Board of Health in certain instances to permit the initial development to take place. These facilities, being less than adequate, are intended to be replaced with permanent facilities as rapidly as the predicted rate of development will permit. In some cases the existing facilities may be heavily overloaded for short periods of time, with the permission of the health authorities. Such an arrangement permits the necessary increase in assessed valuations. Furthermore, since there is no doubt in the minds of the property owners that the temporary treatment facilities are not adequate, permanent treatment plants are frequently achieved promptly. Persons annoyed by temporary facilities are usually quite willing to vote the necessary bonds for permanent facilities.

Covenants

The use of covenants binding the home owners to give the county commissioners the right to include them in future sewer districts have been found to be effective in areas where septic tanks are recognized as having a useful life of several years. Covenants are required to be signed before septic tank permits are granted. Since these covenants are, in effect, a petition to create a sewer district at a future date, the county commissioners are empowered to create districts and construct the sewers when sufficient valuation is available.

Loan Value Effects

Sewered lots have a higher loan value than lots served by septic tanks. This has influenced developers to build sewer systems or to organize sewer districts since builders meet greater sales resistance when they attempt to sell lots served by septic tanks. Competition among developers has stimulated the construction of sewers extensions in communities where sewers were available to some building sites.

Public Attitudes

In areas served by functioning septic tanks, it is difficult to get public acceptance of sewer districts with adequate facilities unless serious nuisance conditions develop. The added tax burden, coupled with the inconvenience of damaged shrubbery, lawns and streets during sewer laying, makes the conversion from individual septic tanks to a public sewer system difficult. Many property owners, whose septic tanks are functioning satisfactorily, believe that the costs exceed the benefits. Numerous public meetings, conducted by well-informed people, are frequently necessary before a growing community gains an understanding of its sanitary problems.

Service Clubs

One of the best means of selling a sewer system to the home owners is through a recognized service club in the community. These clubs are usually composed of the leading citizens of the community and are generally respected.

Publicity

Newspaper and radio publicity can be used to good advantage in explaining the benefits of a sewer district. A series of news stories, with maps showing boundaries of proposed districts, has important benefits. Such maps are usually more effective than any number of words describing the area. Later, when the district has been formed, the maps and articles will show that reasonable means have been used to inform all who are concerned. Failure to get information to all persons affected may well be the major drawback to an otherwise successful campaign.

One interesting sidelight, illustrating the value of maps, occurred recently. The owner of a 120-acre tract of land had been very outspoken in his opposition to the creation of a sewer district, even going to the extent of hiring a lawyer. Several meetings were held explaining the proposed district to the affected property owners. Then a simple form was mailed to all property owners in the proposed area, enabling them to request the inclusion or exclusion of their land in the district. When the results were tabulated it was found that the owners of more than 90 per cent of the land (3,000 acres) were in favor of the plan. Petitions were drawn and a map was prepared. The land of the irate owner was purposely left out and was the only land in the watershed which was excluded. When the map appeared in the paper with a story, the owner was indignant that his land had been excluded. Property values on farm land have risen as much as $1,000 per acre since the district was created. The value of the owner's 120-acre tract has increased by $120,000.

Enforcement of Laws

Administrative action by the State Board of Health and other agencies in strictly enforcing all laws prohibiting the discharge of sewage to ditches or streams will help prevent additional nuisances. In northeast Johnson County a joint policy concerning the use of septic tanks and temporary treatment plants was adopted by the board of county commissioners, the Kansas State Board of Health, and the Johnson County Health Department and has been published and given wide circulation. The policy has been strictly adhered to with beneficial results. The stand taken by these three public bodies has given the general public a better understanding of the problems and has provided guidelines to solving them.

Technical Advisors

For nearly 10 years sanitary engineers of the Kansas State Board of Health have worked with builders, land developers, civic groups and public bodies in solving the sewerage problem in the fringe areas of Kansas City. They have helped to coordinate the efforts of individual builders in forming a few large public sewer districts instead of numerous small, privately-owned systems. They also have labored with bond officials and consulting engineers to plan sewerage systems which could be financed.

Successful Integration

Bringing together several small sewerage systems into one large district has been successfully accomplished in at least three large districts in this area. The problem is relatively simple if the small systems were created initially as public districts under an over-all governing body. In the first large district, fortunately, most of the small areas were organized as sewer

districts under the only available authorized authority, the board of county commissioners. These districts were created before the incorporation of cities and they follow topographical rather than geographical boundaries. At first the districts were widely scattered and created no odor or nuisance problems but, as the population density increased, acute problems arose. Since these areas were public districts, the governing body rather than local residents had the authority to abandon the small treatment plants and connect the sewers to a main system. The costs of connection were borne by the small districts.

In a second large district, the existing sewerage systems were privately owned and operated. However, permits for their operation by the Kansas State Board of Health required assurances of responsible operation. Experience to date has shown that builders who must operate sewage treatment plants until the development of the project is complete, are glad to have a large district created and to abandon their own plants. In one privately sewered area the development is nearing completion. The property owners will soon be faced with the operation of their own treatment plant. A delegation of owners has approached county officials as a preliminary to including their system in a larger sewer district. The major problems with this system are the close proximity of houses to the sewage treatment plant and the poor response to requests for payment of the maintenance fees. The developer has of necessity paid the major share of the operating costs and he is quite anxious to pass on the expense to the property owners.

Sewerage systems covering small areas are sometimes necessary in the development of a community, but they must later be combined into a large public system. The small systems have worked very well to stimulate the construction of sewers. They have made possible the use of sewers instead of individual septic tanks, and they have permitted considerable savings in money. The small sewerage systems are frequently a needed step in the orderly development of an area.

Missouri

This problem of sanitary facilities has been attacked in a different manner across the state line. In Missouri it is possible to create the district without petitions so that advance planning can be done. In some areas where development is beginning, developers are required to build sanitary sewers with due regard to tributary area. The sewers are paid for by the developer and he is given permission by health authorities to construct a temporary sewage treatment plant usually of the lagoon type. As each house is constructed the developer is required to pay a fixed sum to a trustee, usually a bank or trust company. This sum, calculated to be the proportional share of the cost of a permanent sewage treatment plant and trunk sewer system to serve the entire district, is held until the need for a permanent plant is recognized and funds are available. If the treatment plant and trunk sewers are built under a bond issue, the money is subsequently returned to the owner of the property at that time. The return of the money is an inducement to a favorable bond election. In the event that the location of a tract of land in the drainage area requires a large sewer to fit into the over-all plan, the developer may build the large sewer and receive credit for the extra expense involved. This is accomplished by permitting the connection without payment into the escrow fund, of a sufficient number of houses to equal the additional cost. In some cases the developers may elect to retain ownership of the lines and sell them to the district at a later date.

IV. FLORIDA'S FRINGE-AREA SANITATION PROGRAM

By John W. Wakefield

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Florida has been called, in addition to more glamorous titles, the "septic tank state." That this somewhat dubious honor was well earned cannot be denied. Prior to 1946 there were, by estimate, about 250,000 homes in Florida served by septic tanks and individual drain fields. Since 1946, the Florida State Board of Health has cleared septic tank inspection forms on about 12,000 federally insured homes per year. Sanitary facilities for homes financed by conventional loans are not subject to review at the state level, and these probably equal or exceed in number those that are reviewed. Thus, by the end of 1955 the number of individual septic tanks in Florida will probably exceed 500,000.

Prior to 1946, subdivisions were developed by real estate promoters and homes were built at the request of individual lot purchasers. This resulted in a gradual build-up of houses from a condition of a few houses scattered over many lots to a moderate density and thence to a density approaching urban proportions of a house on every lot. This process might take years to accomplish, and public sanitary facilities were difficult to finance due to the lean years of scattered connections. In contrast, since 1946 the development of Florida has been by speculative homebuilders who sell houses instead of lots. Having acquired a promising location, the developer lays out the required facilities and then either proceeds to build houses on practically every lot or he sells groups of lots to other builders who, in turn, build houses on every lot. It is not unusual to see 100 or more houses on adjacent 70-ft. frontage lots in various stages of construction simultaneously. As a result, present subdivisions spring full grown from flat pine woods or pasture land into a densely populated urban development.

Prior to about 1948 Florida, along with most of the other states, continued to try to apply rural sanitary devices to urban developments. Unfortunately even the best soils can become saturated, and when the houses were occupied and the rains came mass failures of subsurface drain fields occurred. Failures occurred even on supposedly high dry land and since the majority of the population of Florida lives within 25 ft. of sea level high dry land is rapidly becoming a rarity.

Suburban Facilities

Under the impetus of the failures that occurred in the normally wet summers of 1948 and 1949, faced with an unprecedented population growth that is now estimated to be at the rate of approximately 1,800 families per week, and in the absence of any governmental unit prepared to assume responsibility for sanitary facilities in suburban developments, the Florida State Board of Health turned to the promotion of privately owned community water and sewerage facilities. The Federal insuring agencies requested a professional opinion of sanitary facilities by the state board of health before they would insure the home loans in any given subdivision. Except for small developments or developments with exceptionally superior soil characteristics the state board of health has recommended public water supplies and public sewerage systems.

As a result, more than 100 subdivisions in Florida are now served by

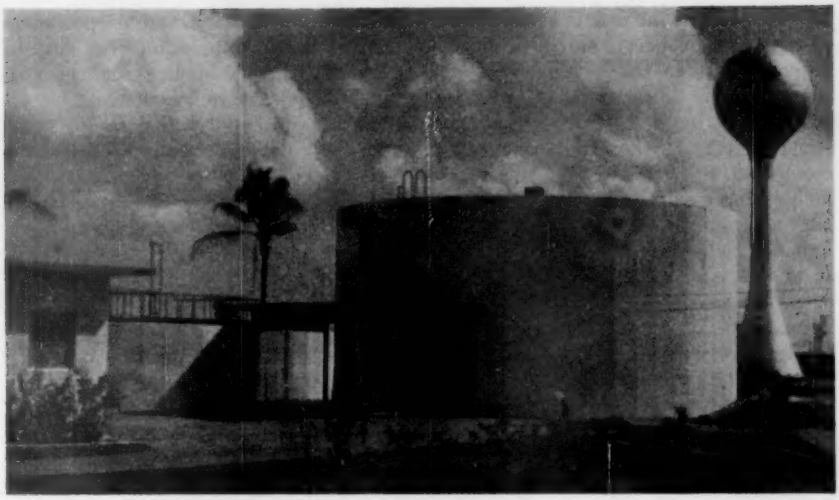

FIGURE 1.—A mechanical aeration activated sludge sewage treatment plant serving a subdivision in Southern Florida.

privately owned public water supplies and public sewerage systems. These facilities, including a sewage treatment plant, are financed through enhanced value of the lot connected thereto and through monthly charges for both water and sewerage service. Privately owned systems at present vary in size from those serving fewer than 50 houses to extensive facilities designed to ultimately serve 10,000 houses. Sewage treatment facilities vary from simple septic tanks and sand filters, or Imhoff tanks with or without secondary treatment, to large activated sludge treatment plants (Figure 1).

The Florida State Board of Health holds no illusions that multiple public sewage facilities are the ideal solution to the suburban development problem. Every sewage treatment plant creates its own operational problems, and the type of residential development now being experienced leads to the development of many independent sewer systems, each with its own treatment plant. These developments are created by individuals and the inevitable personality conflicts and sharp dealings between developers result in situations that do not serve the public interest to the best advantage. For example, one developer needed a right-of-way for an outfall line through another development and in return, for a price, he offered to allow the second development to connect to his sewerage system. In the course of the bargaining that ensued, both sides became impatient. The first developer secured an easement through adjacent property and promptly tripled the price for connection to his system, and the second developer declared he wouldn't do business with the other at any price. The result is two sewage treatment plants within sight of each other with twice as many operational problems. Fortunately both facilities are doing a good job. The state board of health has no valid complaint, but the public in the long run will pay both bills for the duplication of facilities.

A more serious handicap is that each sewage treatment plant requires, or should require, a suitable buffer zone surrounding the treatment units. Occupied buildings should be prohibited in this zone. Consequently,

multiple treatment plants are wasteful of desirable property, and it is always a temptation to the developer to encroach on the buffer zone. Houses are constructed too close to the treatment structures and when that inevitable occasional upset occurs in the treatment processes, there is a deluge of odor complaints and the developer may find himself faced with injunction suits. However, the ever swelling tide of people moving to Florida continues and 1,800 families must have new houses every week. The difficulties and complaints connected with sewage treatment plant operation are far less serious than the alternative difficulties and complaints resulting from individual septic tank and drain field failures.

The author is fully convinced that public health officials in general and sanitary engineers in particular are guilty of permitting and perpetrating a gross misappropriation of a reasonably satisfactory device for the disposal of sewage in rural areas by attempting to apply the septic tank and drain field to urban developments. The rule of expediency has again betrayed us. Having been persuaded that desirable facilities are unobtainable, all available ingenuity has been applied to adapt an admittedly poor expedient as a substitute. The unfortunate victim is the homeowner who confidently purchases the property on the assurance of approval by public health authorities.

Nor is the Florida approach the whole answer. Lacking the authority of legislation permitting uniform control of sanitary facilities in real estate developments, one-half of the homebuilders are told that septic tanks are not satisfactory while the other half

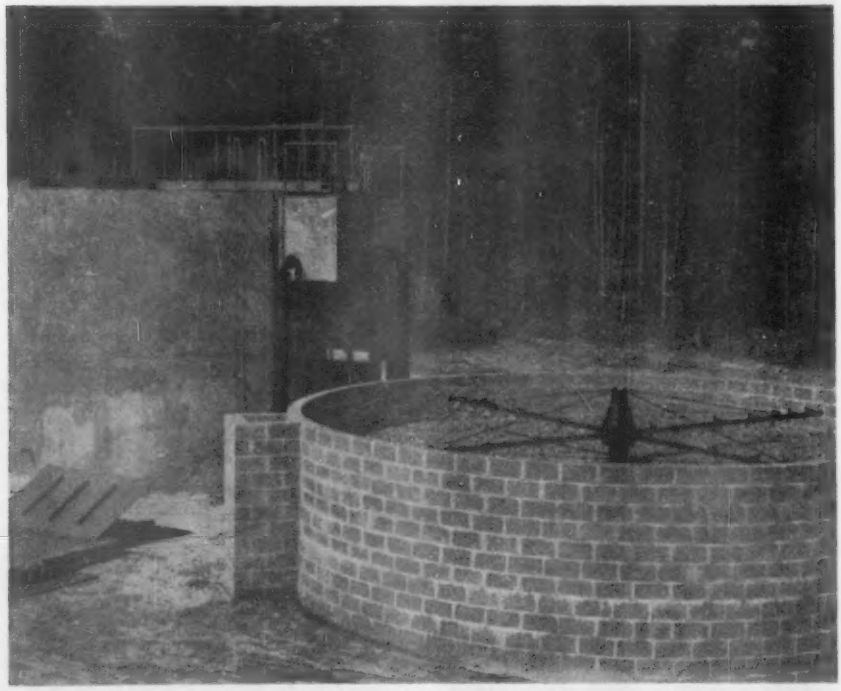

FIGURE 2.—A patented circular Imhoff tank (left) and high-rate trickling filter (right). Secondary clarifier and recirculation pump are to the right out of the picture.

TABLE I.—Summary of Fringe-Area Sewerage Systems in Florida

Location County	Installations (no.)	Range of Design Pop.		Types of Treatment Devices Used					
				Primary			Secondary		
		Initial	Ultimate	Septic Tank	Imhoff Tank	Sep. Setti.	Sand Filter	Trickling Filter	Act. Sludge
Bay	1	550	1,100	—	1	—	—	—	—
Broward	9	424–7,000	1,750–14,000	—	3[1]	6	1[2]	7[3]	1
Collier	1	214	214	—	1	—	1	—	—
Dade	13	500–3,500	1,900–35,000	1[4]	2[5]	10	2	3	8
Duval	27	126–2,100	126–6,300	4	14[6]	10	4	17[7]	1[8]
Escambia	2	1,500–3,000	3,000–4,000	—	—	2	—	2	—
Highlands	1	860	35,000	—	1[9]	—	—	—	—
Hillsborough	7	350–2,100	437–17,500	1	5[10]	1	1[11]	6[12]	—
Manatee	1	3,400	3,400	—	—	—	—	—	—
Orange	3	350–2,000	437–17,500	—	1[13]	2	—	3[13]	—
Palm Beach	2	350–1,440	350–1,440	—	2[14]	—	—	1[14]	—
Pinellas	6	156–1,750	156–2,600	1[15]	4[16]	1	1[15]	4	1
Total	73			7	34	32	10	43	10

[1] One primary clarifier is a patented circular Imhoff tank.

[2] Later construction calls for conversion of the Imhoff tank to a sludge digester; addition of activated sludge.

[3] One installation includes oxidation pond for polishing.

[4] Septic tank and sand filters to serve only 1 to 2 years until municipal treatment plant is complete and sewers extended.

[5] At one plant a patented circular Imhoff tank will be converted to a digester; separate clarifiers and high-rate trickling filters added preceding a sand filter.

[6] Six Imhoff tanks are patented circular tanks.

[7] Four trickling filter treatment plants are standard-rate with dosing siphons, the others are high-rate filters with recirculation.

[8] A contact aeration, secondary treatment process.

[9] An Imhoff tank and chlorination followed by oxidation pond for first-stage construction. (Not yet under construction.)

[10] Three Imhoff tanks are of the patented circular type.

[11] To be converted to sludge drying beds in later stages of development.

[12] Trickling filters are high-rate type.

[13] Imhoff tank is a patented circular tank. Filters are high-rate type.

[14] One patented circular Imhoff tank and a high-rate trickling filter. One Imhoff tank and chlorination.

[15] Individual septic tank and underground sand filter for each home.

[16] Four patented circular Imhoff tanks with high-rate trickling filters.

are continuing to install septic tanks in the same type of developments under state board of health septic tank regulations. Public health agencies should take a clear unequivocal stand against the use of individual septic tanks and drain fields in any situation where the density of housing approaches that of urban developments. If the soil is satisfactory otherwise, the deciding criteria should be the number of houses per acre and not the number of acres involved. Admittedly, such a stand will not be popular with developers, and developers have powerful political influence, but the public trust has been betrayed when economic expediency is permitted to rule in favor of any sanitary device which is known to be less than satisfactory for the intended use.

Costs and Installations

For subdivisions of 300 houses or more, there is little question on the feasibility of a sewer system. When

FIGURE 3.—Completely enclosed primary clarification and separate sludge digestion sewage treatment plant designed to serve a fringe-area population of 2,450. Note proximity of residence (left).

one considers that a septic tank and drain field installation in Florida costs more than $100; that the value of homes served by public sewerage can be enhanced $200 or more; and that a sewer rental charge of $2.00 to $2.50 per month will more than pay operating costs; it becomes obvious that a sewerage system costing approximately $300 to $400 per house is not only feasible but is a paying proposition. Actual contract costs of complete sewerage systems, including either a trickling filter or activated sludge treatment, constructed in Florida within the last five years have varied from $320 per house for a subdivision of 125 houses to as little as $161 per house for a subdivision of 1,200 houses. Most systems for large developments are constructed in stages. Unfortunately the costs of the initial stages are frequently misleading due to the fact that items, such as the piping system, are sized for ultimate capacity but may be charged to the initial development.

Many ingenious schemes have been developed to achieve stage construction of sewage treatment facilities. Final clarifiers or chlorine contact chambers may be used initially as septic tanks. Sludge drying beds may serve the first few houses as sand filters and circular Imhoff tanks, especially the patented tank known locally as the "Spirahoff" * (Figure 2), can later be converted into digesters. Dual clarifiers used initially as primary and secondary clarifiers can be converted later to parallel primary clarifier units. Intermittent trickling filters with low initial B.O.D. loadings are later converted to continuously operated high-rate trickling filters.

Table 1 summarizes the subdivision sewerage systems constructed in Florida fringe-areas within the past five years. Satellite subdivisions discharging to either another subdivision or to a city system have been omitted. These systems have separate sewage

* Manufactured by Yeomans Brothers Co.

treatment facilities and many are very attractively designed (Figure 3).

Conclusion

With regard to operation, admitting that more sewage treatment plants create more problems, in general the subdivision treatment plants have rated equal to or better than comparable sized city plants. As a matter of fact, the owners of the larger privately owned treatment plants, realizing the necessity for good maintenance to protect their investment and unfettered by some of the limitations on salaries imposed by cities, are employing the better operators from the municipal facilities.

The Florida State Board of Health does not consider the privately owned sewerage system as the best answer to the fringe-area problem in Florida. Recent state legislation permitting counties to enter this field of public service offers some hope for a satisfactory solution to the problem. Responsible governmental leaders, however, must be prepared to offer a constructive program of metropolitan water and sewerage systems. Until then, the privately owned and operated public sewerage facility offers a method whereby Florida can continue to grow without being engulfed in a sea of septic sewage.

SANITARY ENGINEERING DEGREES—1955 *

For the academic year 1954–55 there were 141 degrees awarded to graduates from undergraduate sanitary engineering courses. This was a decrease from 1954 when 164 degrees were awarded. All but 12 of the 44 colleges and universities reporting the availability of undergraduate sanitary engineering courses had graduates. There were an additional four colleges reporting courses available in 1954–55. Due to a decrease in the number of graduates during the last two years, the average number of graduates per year for the last 5-year period (1950–54) was 225 compared with 242 reported for 1949–53.

Master's degrees in sanitary engineering were granted to 132 candidates in 1955; 34 of these were nationals of foreign countries. Of the 53 institutions reporting the availability of graduate work in sanitary engineering at this level, 33 (or 63 per cent) had graduates. The number of such degrees granted in 1954 was 120 (25 foreign nationals) and in 1953 the number of degrees was 102 (20 foreign nationals). This indicates a moderate increase in graduate work. The average number of master's degrees conferred per year for the previous 5-year period (1950–54) was 125.

Nine of the 10 doctor's degrees conferred for the academic year 1954–55 by five institutions were to nationals of the United States. Twenty-five other universities offering work at this level had no successful candidates. In the previous 5-year period (1950–54) the average number of doctor's degrees conferred per year was 6.8.

The data presented are tentative.

* From "Master's and Doctor's Degrees in Sanitary Engineering for the Academic Year 1954–55" and "Graduates from Undergraduate Sanitary Engineering Courses for the Academic Year 1954–55" by A. P. Miller, USPHS, Washington, D. C.

COMPARATIVE EVALUATION OF SPECIAL 2-DAY AND STANDARD 5-DAY B.O.D. TESTS

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Zehnpfennig and Nichols (1), in an attempt to obtain a B.O.D. test which was not influenced by the protozoa present in sewage, developed a 2-day test procedure which gave reproducibility that was considerably better than that of the standard 5-day B.O.D. test. They suggested that this improved reproducibility was probably due to the removal of the protozoa and to the preparation of an inoculum containing a preponderance of bacteria which would oxidize sewage. The improved reproducibility of the 2-day B.O.D. test was confirmed by Tidwell and Sorrels (2), but they were unable to agree that the prepared inoculum contained more bacteria capable of oxidizing sewage. Just what causes the improved reproducibility is still unknown.

Since the rate of completion of the normal B.O.D. reaction is established, it is essential to know how well the results of this 2-day B.O.D. test compare with calculated theoretical results for known substrates. Zehnpfennig and Nichols gave some data of this type but did not describe the method by which they obtained the results cited. Moreover, their table of results contained one unfortunate reversal of values which made the interpretation difficult. They also used three substrates for which no exact oxygen demand could be calculated.

The belief that this was an area of study that should be expanded, prompted the work described herein. In addition, a series of analyses on raw sewage, using both the special 2-day and the routine 5-day tests, are described and discussed.

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Known Substrate Studies

On a series of different days, samples of raw sewage were collected at the sewage treatment plant of the Texas A. & M. College. These samples were allowed to settle for four hours at 5° C. and the supernatants siphoned off. A 100-ml. aliquot was placed in a 250-ml. flask and autoclaved. When this had cooled, an aliquot of the raw sewage supernatant was filtered through a fine-pore, sintered glass filter to remove the protozoa. One milliliter of this filtrate was used to inoculate the sterile sewage. This was incubated for 24 hr. at 37° C. One milliliter portions of the non-sterile sewage were used to inoculate a series of B.O.D. bottles containing dilutions of known substrates calculated to give approximately 50 per cent depletion. After incubation, the inoculated, sterilized sewage was used to inoculate a similar, second series of B.O.D. bottles.

In all determinations, sterile B.O.D. bottles, sterile substrates, and sterile dilution water were used. The bottles inoculated with the protozoa-free sewage were incubated for two days at 20° C. The series inoculated with raw sewage supernatant were incubated for five days. Initial dilution water blanks, final dilution water blanks, and final blanks containing the inocula, but with no substrate, were run on each determination. The oxygen depletion was then determined by subtracting

TABLE I.—Comparison of 2-Day and 5-Day B.O.D. Readings with Theoretical Values Using 1,000 p.p.m. of Asparagine as the Substrate

Run No.	B.O.D. (p.p.m.)		Per Cent Error from Theoretical	
	2-Day[1]	5-Day[2]	2-Day	5-Day
1	266	362	1.5	27.0
2	270	395	0.0	20.4
3	283	359	4.8	27.6
4	277	350	2.6	29.4
5	289	367	7.0	26.0
6	282	359	4.4	27.6
7	285	373	5.6	24.8
8	281	330	4.1	33.5
9	244	329	9.6	33.7
10	286	370	5.9	25.4
11	275	299	1.9	39.7
12	289	392	7.0	21.0
13	284	480	5.2	3.2
14	295	370	9.3	25.4
15	287	372	6.3	25.0
16	266	387	1.5	22.0
17	282	390	4.4	21.4
18	266	317	1.5	36.1
19	227	390	15.9	21.4
20	277	414	2.6	16.5
21	295	339	9.3	31.7

[1] Theoretical B.O.D. 270 p.p.m.
[2] Theoretical B.O.D. 496 p.p.m.

the value of the dissolved oxygen of the bottles containing the complete system from the value of the dissolved oxygen of the bottles containing only the inocula. Only those runs showing between 40 per cent and 70 per cent depletion were recorded. Complete results, using asparagine as the substrate, are presented in Table I. A summary of the data obtained with all three substrates is given in Table II.

Comparison of 2-Day and 5-Day Sewage Analyses

Since there are other criteria for sewage strength, a series of samples were tested to determine the B.O.D., by both the standard 5-day and special 2-day procedures. In addition, the settleable solids, fixed solids, volatile solids and total solids were determined for each sample.

Two 100-ml. portions of sewage collected at the sewage treatment plant were removed, without allowing any settling, to flasks and sterilized by autoclaving. When cooled, one flask was inoculated with 1 ml. of raw sewage filtered through a fine-pore, sintered glass filter. This flask was then placed in the 20° C. incubator for 24 hr. The other standard tests were made on the remainder of the raw sewage. After the 24-hr. incubation period the special 2-day B.O.D. test was setup using the uninoculated, sterile sewage as the substrate and 1 ml. of the protozoa-free sewage as the inoculum. Sterile B.O.D. bottles and sterile dilution water also were used with the special 2-day test. In both the 2-day and 5-day B.O.D. determinations, duplicate bottles of at least three dilutions of sewage were used, including routine controls. Only those

TABLE II.—Comparison of Observed and Calculated 2-Day and 5-Day B.O.D. Using Substrates of Known Composition

Substrate	Asparagine	Glutamic Acid	Glucose
Concentration (p.p.m.)	1,000	750	700
C.O.D., calculated (p.p.m.)	730	735	747
5-Day B.O.D., calculated (p.p.m.)	496	503	511
Mean 5-day B.O.D., observed (p.p.m.)	369[1]	369[2]	402[3]
Mean per cent error, 5-day B.O.D.	25.6[1]	26.6[2]	21.3[3]
2-Day B.O.D., calculated (p.p.m.)	270	272	276
Mean 2-day B.O.D., observed (p.p.m.)	276[1]	286[2]	270[3]
Mean per cent error, 2-day B.O.D.	5.3[1]	6.3[2]	10.9[3]

[1] Mean of 21 determinations.
[2] Mean of 11 determinations.
[3] Mean of 5 determinations.

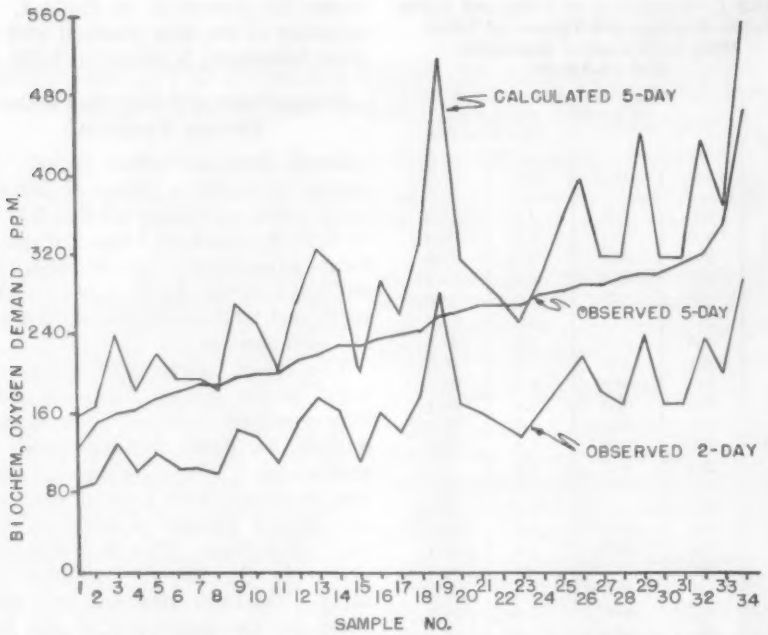

FIGURE 1.—Observed 2-day and 5-day B.O.D. readings obtained on a series of sewage samples, together with a calculated 5-day curve derived from the 2-day readings.

determinations showing between 40 per cent ond 70 per cent depletion were recorded.

From the results, little or no correlation could be shown between any of the solids determinations and either of the B.O.D. readings. In general, high solids determinations were paralleled by high B.O.D. values, but there were marked exceptions over the entire scale covered.

The observed B.O.D. readings are shown in Figure 1 together with a calculated 5-day B.O.D. curve, obtained by multiplying the readings from 2-day B.O.D. test by 1.85 (derived by dividing 68.4 per cent by 37.0 per cent). The samples have been arranged so that the 5-day B.O.D. readings are in ascending order to facilitate easier interpretation.

Discussion

From the results shown in Tables I and II, it is apparent that, with the sewage used as an inoculum, the special 2-day B.O.D. test was considerably better than the 5-day B.O.D. test. With the three substrates studied, the approximate mean percentage error of the 2-day B.O.D. test was 5 to 10 per cent, while that of the 5-day B.O.D. test was 20 to 25 per cent.

The results of the comparative 2-day and 5-day B.O.D. analyses made on raw sewage (Figure 1) show that the two readings agreed fairly well in only about one-half of the analyses. With the remainder of the samples, the 5-day B.O.D. values as calculated from the 2-day B.O.D. values, are consistently much greater than the observed 5-day B.O.D. values. Even with those readings that show fair agreement, the calculated 5-day B.O.D. value is usually higher than the observed 5-day B.O.D. value. This agreement can be explained by one of three means: (a) that both readings are grossly in error, (b) that the observed 2-day B.O.D.

value is too high, or (c) that the observed 5-day B.O.D. value is too low.

From the studies run with known substrates, it is the opinion of the authors that (a) could not be correct, that (b) may be involved, but only to a limited extent, and that (c) must be the primary explanation for those samples where there was wide disagreement between readings. This opinion is based on the fact that in the known-substrate studies the 2-day B.O.D. readings were not grossly in error but were usually slightly higher than the theoretical values, while the 5-day B.O.D. readings were consistently lower than the theoretical readings and usually markedly so.

Conclusions

With the sewage used here as an inoculum, the 2-day B.O.D. technique of Zehnpfennig and Nichols (1) proved to be superior to the routine 5-day B.O.D. test with substrates of known composition. Furthermore, the 2-day B.O.D. test probably gave more nearly correct values when used for the routine analyses of raw sewage samples.

It is interesting to speculate whether or not this 2-day B.O.D. test would give better data with other sewages than the routine 5-day B.O.D. test. Certainly such a result is suggested by the work of Sawyer (3) on primary standards for B.O.D. work where sewage samples from various locations in Massachusetts were used as seed in obtaining an observed 5-day B.O.D. value for standard solutions of glucose and glutamic acid. Of nine sources listed, five samples gave values which were considered "abnormal or beyond the range of experimental error." It is suggested that such sewages not be used as a source of seeding material. The sewage used in the studies performed by the authors would also be considered "abnormal" by Sawyer's standards and yet it, as well as other "abnormal" sewages, must be used as the inoculum in making routine sewage treatment plant analyses. It would be interesting to know how closely studies with other abnormal sewages would compare with the data given here. It may be that other sewages also would give better results with the 2-day B.O.D. technique of Zehnpfennig and Nichols (1).

Summary

Observed B.O.D. values versus calculated values gave mean percentage errors of 5 to 10 per cent for the 2-day B.O.D. tests and of 20 to 25 per cent (Table II) for the 5-day B.O.D. tests.

A series of raw sewage samples were also analyzed for solids and B.O.D., using both the standard 5-day and the special 2-day B.O.D. procedures. Little or no correlation could be shown between any of the solids determinations and either of the B.O.D. readings. The two B.O.D. readings agreed fairly well in approximately one-half of the samples tested, while with the remainder the observed 5-day B.O.D. value was much lower than anticipated from the 2-day B.O.D. readings.

Acknowledgments

The technical assistance of Mrs. Barbara J. Tongate and Mrs. Betty L. Smith and the helpful suggestions of P. J. A. Zeller throughout these studies are gratefully acknowledged.

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RADIOACTIVE ABS IN ACTIVATED SLUDGE SEWAGE TREATMENT *

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The fate of synthetic detergents (syndets) in sewage treatment is of interest from the standpoint of their effect on the operation of sewage plants and possible contamination of receiving waters. Deleterious effects reported in the literature were reviewed by Haney *et al.* in 1954 (1). The most frequent complaint of sewage treatment plant operators is that detergents cause undesirable foam in activated sludge secondary treatment. Also, detergents have been reported to interfere with primary sedimentation and anaerobic digestion of sludge. Lynch and Sawyer (2) suggest that increased oxygen requirements noted at some secondary sewage treatment plants may have been caused by the presence of syndets. Their suggestion is based on results of a laboratory investigation of oxygen transfer in tap water using various commercial household products. Degens *et al.* (3) report that alkylbenzenesulfonate at concentrations greater than 7 p.p.m. interferes with the oxidation of sewage in a pilot-size activated sludge plant by reducing oxygen absorption. The major complaint concerning detergents in water contamination is that they sometimes interfere with water purification procedures and cause taste and odor problems in drinking water. It has also been suggested that detergents in receiving waters may have toxic effects on fish.

Commercial household washing products are the main source of syndets in sewage treatment plants. The detergent is not consumed during the washing process, although it may be partially inactivated as a surfactant by adsorption on or reaction with the soil which is removed during washing. Consequently, almost all the syndets used in households served by sewage treatment plants enter the sewers and are carried into the plants. According to Price, (4) two billion pounds of syndets (80 per cent of the total 1954 production) were used in household products during 1954, the remainder being used for industrial purposes. Alkylarylsulfonates, chiefly ABS (alkylbenzenesulfonates derived from tetrapropylene), were the main type of syndet used in household products in 1954 and comprised 56 per cent of the total syndet production (about 1.12 billion pounds). The remaining 44 per cent was composed of many different types of syndets, alkyl sulfates being the principal type (about 320,000,000 lb. or 16 per cent of the total).

The type and amount of syndet in any particular household washing product may vary from time to time, depending on the requirements of the manufacturer. However, most light duty and heavy duty washing products contain ABS. Total syndet concentration in these products is generally in the range of 15 to 35 per cent, and in many the entire active ingredient is ABS. Therefore, the fate of ABS in sewage treatment is of prime interest in determining the effect of syndets on sewage treatment and water contamination.

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Degens *et al.* (3)(5), Keefer (6) and several other authors (1) have reported various degrees of disappearance of anionic surface active agents in secondary sewage treatment. In addition, Bogan and Sawyer (7)(8) report laboratory results which show that ABS in activated sludge has a biochemical oxygen demand (B.O.D.) which is considerably lower than that of alkylsulfate and ordinary sewage. Both Degens *et al.* (3) and Bogan and Sawyer (7) state that an appreciable fraction of the ABS initially present in sewage can be expected to remain in the effluent from secondary treatment.

The present investigation was carried out in order to obtain additional information regarding the interaction of ABS in activated sludge secondary sewage treatment. Due to the very low concentrations of ABS in receiving waters and sewage influent and effluent, the usual colorimetric methods in determining the presence of syndets are often unsatisfactory as a result of appreciable interference from natural products. By combining the use of radioactive ABS with extractive procedures designed to separate any unchanged sulfonate from non-surface active fragments formed during degradative oxidation, an unequivocal method of tracing the passage of ABS through a sewage treatment process was developed. The technique was applied to a small activated sludge type sewage treatment plant, as well as to a limited laboratory investigation of activated sludge secondary treatment.

The results of these treatment plant studies revealed that:

1. Secondary treatment destroyed 80 to 90 per cent of the ABS entering the small sewage treatment plant. The ABS was oxidized primarily to inorganic sulfate.

2. Both the ABS and the settled sewage were oxidized to about the same degree by the activated sludge treatment.

The results of laboratory studies showed that:

1. Oxidation of ABS was dependent on the dissolved oxygen content of the mixed liquor and an appreciable fraction of the ABS was oxidized in all cases at high aeration rates.

2. The fraction of ABS oxidized varied noticeably in several activated sludge samples taken from one sewage treatment plant on different days.

3. The ABS oxidizing ability of activated sludge appears to be directly related to the presence or absence of ABS in the waste fed during the preceding several days.

4. The fraction of ABS oxidized is not affected by the concentration of ABS in amounts less than about 25 p.p.m.

5. Concentrations of ABS higher than are normally encountered in sewage did not noticeably interfere with oxidation of the sewage. The same result was obtained in combination with detergent builders ordinarily present in commercial detergents.

6. A synthetic sewage containing no ABS was observed to foam considerably more than a natural sewage containing 2 to 4 p.p.m. ABS under the same aeration conditions. This indicates that natural products formed or released during oxidation with activated sludge are sometimes responsible for excess foam in sewage treatment plants.

Details of the investigation are discussed in the following sections, and descriptions of experimental techniques are given in the Appendix.

Plant-Scale Test

The sewage treatment plant chosen for test purposes is owned by the Pacific Gas and Electric Company, and serves about 17 homes at their Kettleman compressor station near Avenal, Calif. Nonresident employees also use this facility so that the total number of persons served throughout a 24-hr. period varies from about 80 to 150

TABLE I.—Kettleman Sewage Treatment Plant, Tank Volumes and Retention Times

Unit	Volume (gal.)	Retention Time
Primary	940	1.5[1]
Secondary aerator	9,850	15.7[1]
Secondary clarifier	1,215	1.5[1]
Anaerobic digester	10,000	6–10[2]

[1] Hours.
[2] Months.

The rated capacity of the treatment plant is 15,000 g.p.d. and the average daily flow is 8,000 to 10,000 gal. The plant is a "package-type" mechanical aeration activated sludge unit with unit retention times as given in Table I.

In this experiment, ABS tagged with radioactive sulfur-35 was fed into the sewage treatment plant continuously over a period of several days. Samples of effluent were collected during this period, as well as for about a week after stopping the addition of tagged sulfonate. The total tagged sulfonate solution, containing about five millicuries of sulfur-35 in 4 g. of ABS, was diluted to about 20 l., and added to the influent raw sewage at the comminutor. The added ABS was less than one per cent of that normally present in the sewage, and was introduced through a rubber tube using a Sigmamotor pump during a 10-day period. The solids and liquid layers in the digester were sampled at the end of the experiment. Effluent samples were analyzed for radioactive ABS, as well as total anionic surface active agent. In addition, effluent samples taken near the end of the tagged sulfonate addition were analyzed for total radioactivity and inorganic sulfur radioactivity. The digester samples were analyzed for total radioactivity to determine how much of the tagged sulfonate ended up in the digester.

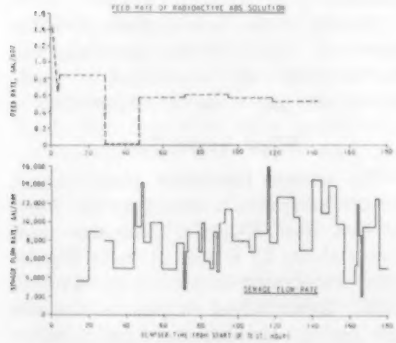

FIGURE 1.—Plant-scale test flow rate and feed of radioactive ABS.

The continuous addition method was employed, rather than a single injection method, to prevent erroneous results due to incomplete adsorption and exchange of radioactively tagged ABS with untagged ABS in the sludge solids. This adsorption effect might mask the results from a single injection of tracer, but with continuous feed a steady state condition should be approached. The concentration of tagged ABS in the effluent was compared to the estimated concentration in the influent to determine the fraction of ABS which was discharged from the treatment plant.

A graphical description of the test in terms of flow rate in the treatment plant and feed rate of radioactive sulfonate solution added at the comminutor in the primary tank is shown in Figure 1. The concentrations of initial radioactivity calculated from these data are compared with those actually measured in extracted ABS from effluent samples (Figure 2). Addition of tagged sulfonate solution was suspended during the interval from 29 hr. to 47 hr. because the effluent line became plugged, resulting in abnormal plant operation during this period. During the interval from 145 hr. to 169 hr., a pump breakdown caused siphoning of a large amount of tagged sulfonate solution at an unknown rate. The final portion of tracer (6.2×10^4 counts per second) was added all at once when the pump was again placed

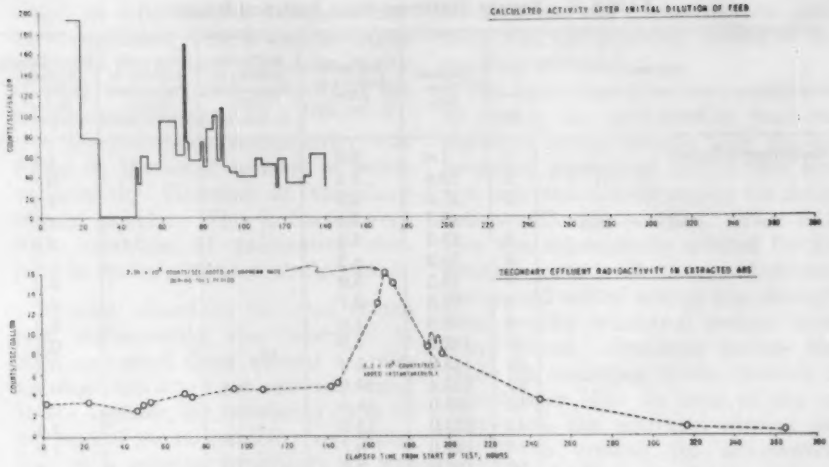
CALCULATED ACTIVITY AFTER INITIAL DILUTION OF FEED
SECONDARY EFFLUENT RADIOACTIVITY IN EXTRACTED ABS
ELAPSED TIME FROM START OF TEST, HOURS

FIGURE 2.—Radioactivity of treatment plant influent and effluent.

in operation. Table II contains a summary of the analytical data with reference to radioactivity and total anionic surfactant.

Significant features noted from these results are:

1. Within 1.5 to 2 hr. after the initial introduction of radioactivity approximately 3 to 5 per cent of the calculated radioactivity appeared in an effluent sample as ABS. This might be due to "short circuiting" in a continuous flow reactor of this type.

2. During the period from 50 hr. to 140 hr., when the treatment plant was operating normally and radioactive sulfonate solution was being fed at a uniform rate, 7 to 10 per cent of the calculated radioactivity concentration was found in the ABS extracted from effluent samples.

3. The total ABS radioactivity leaving the sewage treatment plant in the effluent water throughout the entire experiment was estimated by integrating the area under the curve for secondary effluent radioactivity (Figure 3). Using a daily average flow of 8,700 g.p.d., the effluent radioactivity was found to be 11 to 12 per cent of the total radioactivity added during the experiment (5.8×10^5 counts per second compared with 5.0×10^6 counts per second, total).

4. Radioactivity in the solids from the digester was analyzed by: (a) direct counting of dried solids; (b) counting of barium sulfate obtained from combustion of the solids; and (c) counting ABS-methylene blue complex obtained by the regular $CHCl_3$-MBCl extraction of an aqueous solution obtained from evaporation of an alcohol extract of the solids.

The portions of the total radioactivity found in the digester solids by these procedures were, respectively, 3.2, 1.2 and 0.4 per cent. These percentages were calculated on the assumption that the insoluble digester solids obtained in the bottom 600 gal. of the digester represented about one-half of the total insoluble solids present in the digester. Therefore, the digester appeared to contain approximately 2 per cent or less of the total radioactivity in its insoluble solids and less than 1 per cent in soluble form.

5. Near the end of the addition of tagged ABS, a few effluent samples were analyzed for total radioactivity by counting dried solids. The radioactivity contained in precipitated bar-

TABLE II.—Sewage Treatment Plant Analytical Results

Sample		Elapsed Time (hr.)	Sulfur-35 Activity in ABS[1] (c./sec./gal.)	Sulfur-35 Activity in Evaporated Solids (c./sec./gal.)	Sulfur-35 Activity in Precipitated $BaSO_4$ (c./sec./gal.)	Total Anionic Surface Active Agent,[2] (p.p.m.)
Source	No.					
Secondary effluent	1	1.6	3.2			1.1
	2	22.6	3.4			0.7
	3	47.0	2.5			1.3
	4	49.5	3.1			1.4
	5	53.3	3.4			1.5
	6	70.2	4.2			1.2
	7	73.5	3.9			0.8
	8	94.5	4.7			0.7
	9	118.5	4.6			0.8
	10	142.2	4.9			0.6
	11	145.2	5.3			0.8
	12	165.4	13.0			0.9
	13	169.0	16.0			0.9
	14	173.0	15.0			1.5
	15	189.9	8.7			1.0
	16	191.0	9.9			1.0
	17	191.8	10.0			0.7
	18	192.5	9.8			1.2
	19	193.1	9.3			1.2
	20	194.0	9.1			1.2
	21	194.8	9.7			1.3
	22	195.4	9.8			1.2
	23	196.1	8.8			1.4
	24	197.1	8.1	77		1.5
	25	245	3.5	23.5		1.7
	26	317	0.8			1.4
	27	365	0.5			2.3
	28	386.5	0.6			3.3
Primary tank	29	22.6	20.0			4.9
	30	49.5	22.0			16.9
	31	70.2	41.0			2.2
	32	142.2	30.0			4.5
	33	145.2	25.0			11.3
	34	165.4	36.0			2.3
	35	169.0	11.0			22.8
Supernatant liquor	36	386.5	1.1			2.0
Filtrate from slurry of bottom 600 gal. of digester sludge	37	387	4.4	2.5		2.9
Secondary effl. blend[3]	38	—	9.4		52	1.3
Solids from slurry of bottom 600 gal. of digester sludge	39	387	17.8			47

[1] Average initial activity in the sewage for the first 140 hr. was about 60 counts per second per gallon (c./sec./gal.) compared to an average of about four c./sec./gal. found in ABS in the effluent during the same period.

[2] Determined by the colorimetric method.

[3] Samples No. 19, 21, 22 and 23.

ium sulfate, following oxidation in a neutral solution with hydrogen peroxide, was also counted, thus measuring the radioactive inorganic sulfur compounds. The purpose of these tests was to obtain a material balance and determine to what extent the ABS was oxidized to inorganic sulfur compounds. In a sample obtained after about 195 hr. of test, the radioactivity as ABS was about 10 per cent of the total radioactivity recovered from the evaporated solution and about 15 per cent of the sum of the radioactivity

found as ABS and as inorganic sulfur compounds. In a sample taken after 245 hr. of test, the radioactivity as ABS was about 15 per cent of the total radioactivity.

6. No detectable radioactivity was found in the small amount of solids obtained by filtration of secondary effluent samples. This indicated very little retention of radioactive compounds in the activated sludge solids.

Because almost 12 per cent of the total radioactivity was recovered in ABS extracted from effluent samples and less than 3 to 4 per cent was found in the digester, the remaining 84 to 86 per cent of the radioactivity was either lost as a gaseous byproduct or was present in the effluent as a sulfur compound other than ABS. On the basis of the analysis of effluent samples taken shortly after halting the addition of tagged ABS, the radioactivity as inorganic sulfur, either sulfate or compounds oxidizable to sulfate by hydrogen peroxide, was 85 to 90 per cent of the total radioactivity. If this quantity prevailed throughout the entire experiment, then 80 to 100 per cent of the total radioactivity is accounted for. The results strongly suggest that about 85 to 90 per cent of the ABS is oxidized to give inorganic sulfur compounds. The sewage treatment plant was operating at only moderate efficient (70 to 75 per cent) removal of sewage organic matter. The effluent B.O.D. was 50 to 60 p.p.m. compared with a normal raw sewage of about 200 p.p.m. Apparently ABS was being attacked with about the same or slightly higher efficiency than the oxidizable sewage.

Laboratory Investigation

The objective of the laboratory investigation was to test further the ability of organisms in activated sludge to decompose ABS. This is of special interest because the plant-scale test showed that only a small amount of sulfonate was removed in the primary settled solids and that secondary treatment was the principal means of destroying sulfonate.

The laboratory tests were conducted by mixing the settled solids from the activated sludge sample with the appropriate amount of settled raw sewage, and immediately adding the radioactive sulfonate solution. This mixture was subsequently aerated for the desired period of time. Activated sludge and settled sewage was obtained from nearby municipal sewage treatment plants. Synthetic sewage was made up according to the formula of Weinberger (9). In most of the experiments, the activated sludge was settled to remove the supernatant liquid and then stored overnight at 33° F. The settled sewage was either used immediately or stored overnight at 33° F. A quantity of sludge was chosen to give a 30-min. settleable solids value of 100 to 120 ml. for 500 ml. of mixed liquor in a 500-ml. graduate. A comparison of the oxidizing power of samples containing 50, 100 and 160 ml. of settleable solids revealed 8-hr. sulfonate decompositions of 32, 40 and 40 per cent, respectively, indicating that small variations in settleable solids above 100 ml. would not have a noticeable effect on sulfonate decomposition. Reproducibility of the test was good, as shown by duplicate experiments carried out with samples of the same sludge and sewage mixture at the same aeration rates. The two runs gave 41 and 42 per cent sulfonate decomposition, respectively.

Aeration

Unlike the plant-scale test, where the operating conditions were fixed by the requirements and physical equipment of the treatment plant, it was necessary in the laboratory experiments to establish the effects of aeration variables on the activity of the activated sludge. Figure 3 shows the variation in D.O. content at different constant aeration rates throughout an 8-hr. aer-

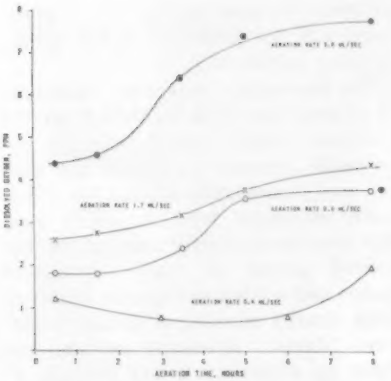

FIGURE 3.—Variations in D.O. content at different aeration rates during an 8-hr. aeration period.

ation period. A general pattern of increasing dissolved oxygen with time may be noted. This is in agreement with the concept of decreased utilization of oxygen by the sludge as the sewage concentration decreases. An indication of the different aeration requirements for different size batches and reactors is shown in Figure 4.

Oxidation of Sewage and Sulfonate

The aeration rate (as measured by the 30-min. D.O. value) had considerable effect on the reduction in sewage organic matter and decomposition of tagged ABS during the 8-hr. aeration period as shown in Figure 5. In the case of sewage, the degree of oxidation increases greatly with the aeration rate up to a breakpoint rate of about 2 p.p.m. of dissolved oxygen (30-min. value). Above this rate the curve levels off and is only slightly affected by further aeration rate increases. In the case of ABS, a steady increase in decomposition is observed with increasing 30-min. D.O. values up to the point of oxygen saturation. The magnitude of sulfonate decomposition varied considerably from one batch of activated sludge to another, but the increase in decomposition with aeration was observed in all cases. Conceivably, a sample of sludge which was efficient at oxidizing sulfonate might produce 80 or 90 per cent decomposition at low aeration rates and yield a curve similar to that shown for sewage oxidation. Generally, the 8-hr. oxidation of sulfonate was never comparable to that of sewage except at high aeration rates.

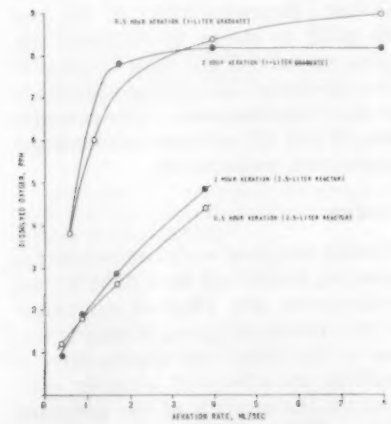

FIGURE 4.—Variations in aeration requirements for different size laboratory aeration units.

Variation in sewage oxidation with various samples of sludge was considerably less than that observed with sulfonate. Five different sludge samples each gave 8-hr. B.O.D. reductions of 78, 92, 87, 86 and 85 per cent when aerated above the breakpoint rate. The decomposition of sewage and sulfonate with time is shown in Figure 6 for a sample of sludge having a relatively high capacity for decomposing ABS. All samples were taken during a run in which aeration was sufficient to give a 30-min. D.O. value of about 5 p.p.m. The principal difference appears to be that the sulfonate is oxidized at approximately a constant rate throughout the 8-hr. period; whereas, sewage is oxidized most rapidly during the first 2 hr.

Day-to-Day Variation in Sludge

Activated sludge samples collected from a particular treatment plant

varied from day to day in their ability to oxidize ABS (Figure 5). This might be due to day-to-day differences in the sewage fed to the activated sludge or variations in the conditioning of the sludge due to the presence or absence of sulfonate in the sewage.

In an experiment using identical activated sludge and sewage samples, the decomposition of sulfonate was compared in the presence of initial concentrations of sulfonate of 1 to 4 p.p.m. and 21 to 24 p.p.m. Within experimental error, the per cent decomposition of sulfonate was unaltered by the presence of the larger amount of sulfonate (76 per cent compared with 75 per cent).

Because the sulfonate content of sewage may vary considerably from day to day, the presence or absence of sulfonate during previous feedings might affect the ability of the activated sludge to oxidize sulfonate. Accordingly, in three separate experiments, the activated sludge was fed sewage containing added sulfonate for seven days (Table III). Synthetic sewage was used in order to assure the complete absence of sulfonate in the control. In two out of three cases the activated sludge exhibited an appreciable increase in its ability to decompose sulfonate after being fed for seven days with sewage containing 5 p.p.m. sulfonate. In the one case tested, the absence of sulfonate in the sewage apparently caused an appreciable reduction in the sulfonate decomposing capacity of the activated sludge.

TABLE III.—Effect of Feeding Activated Sludge for Seven Days on Synthetic Sewage with and without Added ABS

Test No.	ABS in Sewage (p.p.m.)	Aeration Rate 2-Hr. D. O. (p.p.m.)	8-Hr. Sulfonate Decomposition (%)	
			Start of Feeding	End of Feeding
1	5	—	29	89
2	5	6.9	64	56
3	5	6.4	38	89
4	(nil)	6.4	89	21

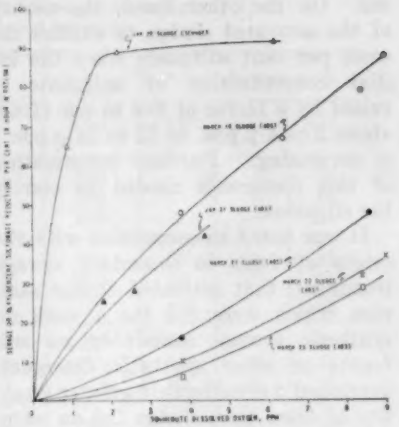

FIGURE 5.—Effect of aeration rates on the oxidation of ABS and sewage.

The above results are insufficient to establish all of the variables which may affect the day-to-day character of activated sludge in a particular treatment plant. However, the continued presence or absence of ABS in the sewage appears to be of some importance in determining the capacity of the activated sludge for decomposing sulfon-

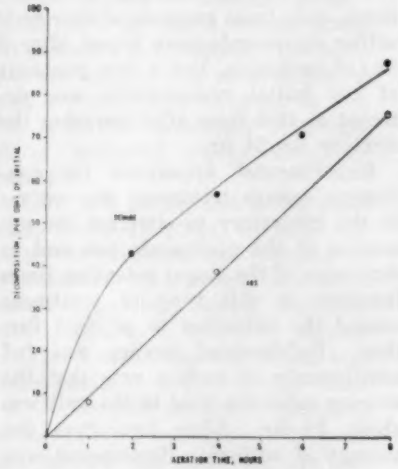

FIGURE 6.—Oxidation of sewage and ABS for various aeration periods.

ate. On the other hand, the ability of the activated sludge to oxidize the same per cent sulfonate when the initial concentration of sulfonate is raised by a factor of five to ten (from about 2 to 4 p.p.m. to 22 to 24 p.p.m.) is surprising. Further investigation of this feature is needed to clarify the situation.

It was noted in connection with the origin of foam in secondary sewage treatment, that activated sludge samples, which were fed for a week on synthetic sewage containing no sulfonate or other synthetic detergent, developed a considerably greater quantity of foam than sludge fed on natural sewage containing 2 to 4 p.p.m. sulfonate. This would seem to support the hypothesis that foam may be partly caused by natural products formed or released in the secondary treatment of sewage.

Products of the Oxidation of Sulfonate

Samples taken near the end of the plant-scale test contained radioactive inorganic sulfur compounds in approximately the correct amount to account for the missing sulfonate. These results indicated that the sulfonate molecule had been completely oxidized. However, in the laboratory experiments only trace amounts of inorganic sulfur compounds were found after 8 hr. of oxidation, but a few per cent of the initial radioactivity was detected in this form after aerating the mixture for 24 hr.

Experimental apparatus for continuous sewage treatment was set up in the laboratory to simulate the operation of the plant-scale test and to determine if the longer retention times inherent in this type of treatment caused the oxidation to proceed further. Refrigerated sewage was fed continuously at such a rate that the average retention time in the unit was about 15 hr. After two days the amount of sulfonate decomposed was constant at 45 to 50 per cent, and after about three days the amount of inorganic sulfur compounds formed leveled off at about 5 to 7 per cent. The aeration rate was relatively low in this experiment, and it is possible that higher aeration rates would convert more of the oxidized sulfonate to inorganic sulfur compounds.

Passing the exhaust air from a batch experiment through a caustic solution revealed that no radioactivity was lost as volatile acids during the aeration. However, upon evaporating the solution remaining after extraction of the sulfonate, only a portion of the missing radioactivity was recovered; as much as 50 per cent being lost in some cases. Perhaps the volatile oxidation products containing sulfur were lost during the evaporation of the water to obtain a dry residue which could be counted (see Appendix). If this were true, then a direct count on the solution before heating should locate the missing radioactivity. Two samples counted directly in this manner with a liquid scintillation counter gave material balances of 91 and 94 per cent. It is, therefore, apparent that in the laboratory experiments the sulfonate molecule is only partially oxidized; and in some cases, a volatile product containing sulfur is formed which is lost during evaporation.

Oxidation at Marginal Aeration

From the curve of sewage oxidation versus aeration rate shown in Figure 5, it is apparent that aeration rates which yield a 2-hr. D.O. value of about 2 p.p.m. are marginal. That is, any factor causing a reduced D.O. content, such as reduced oxygen transfer, reduces the sewage oxidation efficiency, as measured by the reduction of the B.O.D. in 8 hr.

Experiments were carried out under these marginal aeration conditions with and without added ABS to determine if an activated sludge system operating at marginal aeration is adversely affected by ABS in concentrations and in formulations which might be encountered in actual practice. The

TABLE IV.—Effect of Added ABS on Sewage Oxidation by Activated Sludge at Marginal Aeration

Activated Sludge Unit	Added Product		Total Anionic Surface Active Agent[1]	2-Hr. D. O. (p.p.m.)	Initial B. O. D. (p.p.m.)	B. O. D. Reduction. (%)		
	Product	Conc. (p.p.m.)				1.5 Hr.	4 Hr.	8 Hr.
1	None	0	—	2.1	220	—	—	82
2	None	0	—	2.2	210	—	—	84
3	None	0	—	2.1	210	—	—	86
1	Control	0	2.4	1.9	185	33	59	81
2	ABS	5	2.4	1.8	190	36	57	77
3	ABS	15	2.4	1.9	195	33	57	76
1	Control	0	3.4	1.9	210	36	57	81
2	Formula No. 1	25	3.4	2.0	220	36	59	84
3	Formula No. 1	75	3.4	1.9	235	38	60	85
1	Control	0	2.7	1.9	190	33	53	82
2	Formula No. 2	25	2.7	1.9	195	33	54	80
3	Formula No. 2	75	2.7	2.0	200	29	53	79

[1] Methylene blue extraction method.

Detergent Formulations Used in Test

Formula	ABS (%)	Tallow Alcohol Sulfate (%)	Sodium Sulfate (%)	Sodium Tripoly Phosphate (%)	Sodium Pyro-phosphate (%)	Sodium Silicate (%)	Lauric Isopropanol Amide (%)	Lauryl Alcohol (%)
No. 1	10	10	23	30	20	5	0	2
No. 2	17	0	25	30	20	5	3	0

experiments utilized three 2,500-ml. glass aeration units; the same activated sludge and sewage was used in each unit for a set of three experiments. A control run was carried out in the first aeration unit in each case. The mix was stirred for about 5 sec. every 15 min. to prevent the sludge from settling.

Results of these experiments (Table IV) revealed that there is very little, if any, detrimental effect exerted by the sulfonate at concentrations close to those used in practice. In addition, phosphate detergent builders, such as those used in some heavy duty commercial detergents, showed no adverse effects.

Summary and Conclusions

1. By combining the use of radioactive ABS with extractive procedures designed to separate any unchanged sulfonate from fragments formed during degradative oxidation, an unequivocal method of tracing the passage of ABS through a sewage treatment process was developed. The technique was applied to a small activated sludge sewage treatment plant, as well as to a limited laboratory investigation of activated sludge secondary treatment.

2. During a 10-day test in the small sewage treatment plant, 80 to 90 per cent of the sulfonate was removed by the secondary treatment, the main product apparently being inorganic sulfur compounds, probably sulfate. Only traces of sulfonate or sulfur containing oxidation products were found in the anaerobic digester, indicating that secondary treatment was the principal method for removing the sulfonate from the sewage.

3. In laboratory experiments, acti-

vated sludge from a particular sewage treatment plant was found to vary considerably from day to day in its capacity for oxidizing ABS. The ability of the sludge in this respect was almost directly dependent upon the aeration rate, as measured by the 30-min. D.O. content of the mixed liquor. At low aeration rates, sulfonate removal of sludge samples varied from about 2 to 30 per cent compared to about 30 to 90 per cent removal at high aeration rates. On the other hand, sewage oxidation, as measured by B.O.D. reduction, became almost constant at aeration rates greater than those required to produce a 30-min. D.O. content of 2 p.p.m. In this aeration range the observed sewage oxidation was as low as 78 per cent.

4. The ability of activated sludge to decompose the sulfonate can be reduced appreciably by prolonged feeding with synthetic sewage containing no sulfonate and can be increased by the continued addition of 5 p.p.m. sulfonate to the sewage feed. Therefore, it is likely that the concentration of ABS present in the sewage may have some effect on the capacity of the sludge. The addition of 20 p.p.m. sulfonate to natural sewage containing 1 to 4 p.p.m. sulfonate did not alter the percentage reduction in sulfonate during 8 hr. of treatment with activated sludge.

5. In laboratory tests, none of the sulfonate was oxidized to inorganic sulfur in 8 hr., although a small percentage was formed in 24 hr. Some volatile sulfur compounds were formed, as indicated by their removal during evaporation of the aqueous sample in the laboratory.

6. Concentrations of ABS greater than those normally encountered in normal sewage treatment practice were found to exert no noticeable detrimental effect on sewage oxidation at marginal aeration rates. This result was obtained with the sulfonate alone and in combination with detergent builders common in commercial heavy duty detergents.

Further investigation is necessary, but it seems clear that activated sludge secondary treatment can, under some circumstances, remove most of the ABS present in normal sewage. The conditions necessary to maintain a sludge capable of high efficiency in this respect are still to be determined; however, a high D.O. concentration in the mixed liquor is known to promote increased oxidation of the sulfonate.

Acknowledgment

The authors wish to acknowledge the many helpful suggestions from Dr. B. K. Shahrok, Bio-Research Laboratories, Berkeley, Calif., who made the B.O.D. and D.O. determinations. We are also indebted to the Pacific Gas and Electric Co. for the use of their facilities in carrying out the plant-scale test.

APPENDIX—RESEARCH TECHNIQUES

Preparation of Radioactive ABS

Alkylbenzenesulfonate containing sulfur-35 was prepared by a modification of the procedure of Meader and Fries (10). Twenty per cent radiosulfur oleum was used to sulfonate the alkylbenzene (Oronite Alkane) in the presence of excess alkylate. The acid mixture was then dissolved in ethyl ether and extracted with three portions of 2N HCl to remove all sulfate (11) (12). After removal of the ether by evaporation, the sulfonic acid residue was heated for 15 min. on a steam plate to remove water and HCl. The sample was then dissolved in 70 per cent alcohol and neutralized with 0.5N NaOH. Removal of oil was then carried out by isopentane extraction of the ethanol solution.

Plant-Scale Test

Flow Measurement

Flow through the sewage treatment plant takes place by overflow from one unit to the next so that influent and effluent flow are equal. A recorder automatically registers the flow at the effluent weir. The flow rates shown in Figure 2 were obtained by averaging out small variations in the flow records. The records were spot checked by means of periodic direct measurements of flow rates at the effluent weir.

Sampling

Secondary effluent samples were taken at the effluent weir, and primary tank samples were obtained at the side nearest the overflow to the aeration tank. The digester was emptied of most of the solids a few days before the experiment and again seven days after the last addition of radioactive solution. The supernatant liquid at the top of the digester was sampled at the same time and found to contain only a small amount of solids.

Analytical Procedures

Separation of ABS from Other Sulfur Containing Compounds

Make up a 3-l. sample containing 0.5N H_2SO_4 and 6 p.p.m. methylene blue chloride. Shake thoroughly for 2 min. in the presence of 100 ml. of $CHCl_3$ in a 4-l. separatory funnel. Settle for 5 to 10 min., withdraw the $CHCl_3$ and cuff layers, and reseparate in a 250-ml. separator funnel if necessary. Add 2 mg. of nonradioactive ABS to the separated aqueous layer and repeat the extraction twice more using 80 ml. of $CHCl_3$ each time. The methylene blue concentration must be replenished in the aqueous layer if most of the blue color disappears due to high ABS concentrations. Wash the combined $CHCl_3$ extracts with 25 ml. of 0.4N H_2SO_4 and wash the H_2SO_4 solution with 10 ml. of $CHCl_3$.

Analysis of Extracted ABS for Radioactivity

Add a weighed amount (about 100 mg.) of powdered charcoal (Norit A) to the final $CHCl_3$ solution and evaporate the mixture on a steam plate to a volume of about 25 ml. Add 25 ml. of ethanol and evaporate to 10 to 15 ml. Add 25 ml. of water and evaporate to about 5 ml., stirring the mixture during the evaporation to facilitate the adsorption of the ABS-methylene blue product on the carbon. Transfer the slurry onto an aluminum sample disk contained in a "platemaker." (The details of sample plate preparation are described by Calvin *et al.* [13]). Evaporate the slurry to dryness using agitation to produce a uniform plate. Weigh the tared sample plate plus sample to determine the sample weight and count using a mica end-window Geiger counter. From the sample weight and area of the plate, calculate the surface density and correct the count rate for self-absorption obtained from a graph of self-absorption correction versus surface density. Calculate the total radioactivity in the sample by multiplying the corrected count rate by the ratio of weight of total carbon plus ABS-methylene blue to the weight of sample on the plate.

Accuracy

The extraction method was found to give 90 to 100 per cent recovery of radioactive tagged ABS. The standard deviation of sample counting was ± 5 per cent.

Laboratory Tests

Reactors and Aeration

Batches containing samples of 2- to 3-l. were run in glass turboreactors which were stirred for only 5 sec. every 15 min., just sufficient to prevent settling of the sludge solids. Small batches (100 to 200 ml.) were tested in 250-ml. graduates, and intermediate batches (800 ml.) in 1-l.

graduates. Samples were aerated by pumping air through coarse sintered glass-tipped bubbler tubes. Air was pumped either by glass syringes actuated by a variable speed motor or by pumping through rubber tubing using a Sigmamotor pump. With the syringe pump it was possible to obtain flow rates reproducible within about 5 per cent. In the case of the Sigmamotor pump, about 10 per cent variation was found using the same size tubing.

Test Procedure

The activated sludge was obtained from a municipal sewage treatment plant and used within a few hours or settled and stored overnight at 33° F. The settled activated sludge solids were mixed with the sewage at the start of the experiment and the tagged sulfonate was then added and aeration started. To each sample that was taken, 0.5 ml. of 40 per cent formaldehyde solution was added per 100 ml. of sample to halt bacterial action.

The sludge solids were separated from the solution by vacuum filtration using 500 mg. of Celite filter aid per 100 ml. of solution in order to achieve rapid filtration. Five milligrams of nonradioactive sulfonate were added before filtration, and approximately one-third of the total sulfonate was adsorbed on the filter cake. The radioactivity on the filter cake was shown to be essentially all sulfonate by the fact that only 3 per cent of the 89 per cent of the radioactivity recovered by alcoholic extraction of the filter cake was lost during subsequent extraction with ether from aqueous HCl solution.

Separation of ABS from Other Sulfur Compounds

For the laboratory investigation, an improved analytical method was used. Extraction with ethyl ether from aqueous HCl solution was employed to separate the ABS from any lower molecular weight sulfonate fragments or inorganic sulfur compounds formed by oxidation of the sulfonate.

Transfer the filtrate from the sample to a 500-ml. separatory funnel and acidify with 10 ml. of 12N HCl. Extract three times with 50-ml. portions of ethyl ether and wash the combined ether extracts thoroughly with two to three 20-ml. portions of 2N HCl.

In the cases where analysis for radioactive inorganic sulfur is desired, add about 0.2 g. of Na_2SO_4 to the combined aqueous phase, and after heating in the presence of bromine water to oxidize all inorganic sulfur to sulfate add 10 ml. of 10 per cent $BaCl_2$ solution slowly to the boiling solution to precipitate $BaSO_4$.

Preparation of Samples for Counting

Ether Extract

Transfer the ether extract to a tared, 250-ml. beaker containing about 150 mg. of powdered carbon (Norit A) and evaporate to dryness on a steam plate. Moisten the carbon residue with about 10 ml. of acetone, then add 15 ml. of water and swirl to contact all of the carbon with the solvent. Evaporate to dryness on the steam plate, cool and weigh. Grind the carbon in a mortar and store in a stoppered vial.

Sludge-Celite Filter Cake

Dry the filter cake at 110° C. (about 1 hr.), cool and weigh. Grind the dry sample to a powder in a mortar and store in a stoppered vial.

Barium Sulfate Precipitate

Filter the precipitated $BaSO_4$ under vacuum through Whatman No. 2 filter paper on a 3.5 cm. Bitumen crucible and wash thoroughly with hot water. Dry the sample at 110 to 140° C., powder the dry precipitate on a piece of glazed paper with a spatula, and store in a stoppered vial.

Plate Making and Counting

Plate Holder

Two plate holders are used, one for the carbon and Celite samples and the other for the $BaSO_4$ samples. These holders consist of disks machined from brass or steel with flat depressions of the appropriate depth for holding the powdered sample to be counted. Disk diameter is 1⅛ in. with the diameter of the depression being 1 in. The disks are ⅛-in. thick and depths of the depressions are 0.025 in. and 0.012 in., respectively. The deeper disk holds about 75 mg. of carbon and 150 mg. of Celite, and the shallow disk holds about 180 mg. of $BaSO_4$. Because these samples are all above the point of "infinite thickness" for self-absorption of the sulfur-35 beta rays, small variations in weight of sample do not affect the count obtained, and it is not necessary to determine the weight of each plate.

Plate Making

For the carbon sample, place about 100 mg. of sample on the deep plate holder and spread the carbon uniformly with the side of a straight, glass stirring rod until the depression is completely covered. Then carefully scrape the side of the stirring rod across the plate holder with the rod touching the shoulder of the plate holder in order to leave a flat surface of carbon, level with the shoulder.

To form a plate from Celite or $BaSO_4$, work the sample uniformly into the depression with the flat end of a small spatula and obtain a level surface by sliding the spatula back and forth over the surface, using the shoulder of the plate holder as a guide. The deep plate holder should be used for Celite samples and the shallow one for $BaSO_4$.

Counting

The samples are counted using a mica end-window Geiger tube with the plates centered about 1 mm. below the window of the tube. The samples and the standard with which they are compared must be counted at exactly the same distance below the window.

Because the standard radioactive sulfonate solution is adsorbed on the powdered carbon and counted in the same manner as the other samples, it is only necessary to know the relative self-absorption corrections at "infinite thickness" for the three materials in order to obtain consistent results. These values were obtained as a first approximation by mixing 10 parts of powdered carbon containing high radioactivity with 90 parts of each of the other materials and comparing the activity of the mixtures with that of the original carbon sample. From this work, a correction factor of 0.91 was found for Celite samples and 0.81 for $BaSO_4$ samples.

Accuracy

The extraction procedure gives 99 per cent or better recovery of ABS from solution. The standard deviation of sample counting was about ±2 per cent in the case of the carbon samples and ± 4 per cent for the $BaSO_4$ and Celite samples.

B.O.D. and D.O.

Values for the B.O.D. of the samples were determined by the standard method using an incubation period of five days at 20° C. (14). D.O. was determined by the Winkler method.

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USPHS INACTIVE COMMISSIONED RESERVE

Qualified sanitary engineers and other professional health personnel actively engaged in public health practice and preventive medicine are being encouraged to apply for commissions in the Commissioned Reserve of the U. S. Public Health Service.

The Commissioned Reserve is being expanded to increase the readiness of the nation to meet the unusual public health demands of national emergencies. The USPHS is interested in encouraging greater participation in the program by professional groups. In the event of national emergencies, the Commissioned Reserve would have the opportunity of serving in the capacities for which their professional training and experience have fitted them.

The Reserve officers will be called for emergency duty to reinforce the staffs of official state and local health agencies and to augment the Public Health Service operating staff. Commissioned reserve officers would not be called to emergency active duty, with the exception of volunteers, unless the situation is publicly recognized as requiring action.

Expansion of the Commissioned Reserve began approximately 18 months ago, since then field training courses and other activities for reserve officers have been instituted. Advance sanitary engineering training courses at the Sanitary Engineering Center have been planned for reserve sanitary engineering officers during June, 1956. Other training opportunities for reserve personnel will continue to be made available.

Inquiries concerning the Inactive Reserve should be addressed to the Surgeon General, Public Health Service, U. S. Department of Health, Education and Welfare, Washington 25, D. C., or to the nearest regional office of the Public Health Service.

Industrial Wastes

PETRO-CHEMICAL WASTE TREATMENT PROBLEMS *

By G. E. Montes, D. L. Allen, and Edward B. Showell

Respectively, Chief Technologist and Senior Technologist, National Petro-Chemicals Corp., Tuscola, Ill., and Consultant, Chadds Ford, Pa.

The problems of water supply and waste disposal are universal. Those of National Petro-Chemicals Corp. at Tuscola, Ill. are perhaps unique in that water must be supplied and wastes treated for a diversified petro-chemical area (Figure 1) of about $75,000,000 investment, utilizing a river which at times has almost zero natural flow. National Petro-Chemicals Corp. produces butane, propane, natural gasoline, ethyl alcohol, ethyl chloride and polyethylene. Associated with the plant is a U. S. Industrial Chemicals Division ammonia plant and a sulfuric acid plant.

Feed stock to the petro-chemical plant is 400,000,000 cu. ft. per day of natural gas. Liquid hydrocarbons from ethane to the gasoline range are extracted from this gas by low temperature absorption. Pyrolysis of ethane produces 350 tons of ethylene per day which comprise the feed to the three chemical units. The ethylene unit is the largest single ethylene unit known to be in production. The synthetic alcohol unit is also the largest and produces about 40,000,000 gal. per year of 190 proof ethyl alcohol. Ethyl chloride production is approximately 50,000,000 lb. per year. The acid plant supplies sulfuric acid used in the alcohol unit, and has a capacity of 450 tons per day. The ammonia plant is designed for 200 tons per day of anhydrous ammonia.

National Petro-Chemicals Corp. is owned jointly by National Distillers Products Corp. and Panhandle Eastern Pipe Line Corp. Its location near Tuscola, Ill. was determined by the presence of the junction of rich and lean gas pipelines. High B.t.u. gas is blended with the plant outlet gas to adjust the B.t.u. level to that set by the Federal Power Commission.

Location of a chemical processing plant "in the cornfields" meant that it must be self-sufficient for utilities. All steam (750,000 lb. per hour) and most of the electric power (up to 12,000 kw.) are produced by facilities at the plant. The water is supplied and plant wastes are treated by the Industrial Water Supply Co. Fresh water is used at the rate of approximately 6 m.g.d. and the waste water discharge is 3.25 m.g.d. The supply of water and disposal of waste is enormously complicated by location of the plant near the head of the Kaskaskia River. This river can have an almost zero natural flow in the summer, due to the fact that only about two per cent of the Kaskaskia River drainage basin is upstream from the plant site. To supply water in these periods of drought, two company owned wells rated at 6.4 m.g.d. discharge into the headwaters of the Kaskaskia River. This water is pumped out of the river

* Presented at 28th Annual Meeting, Federation of Sewage and Industrial Wastes Assns.; Atlantic City, N. J.; Oct. 10–13, 1955.

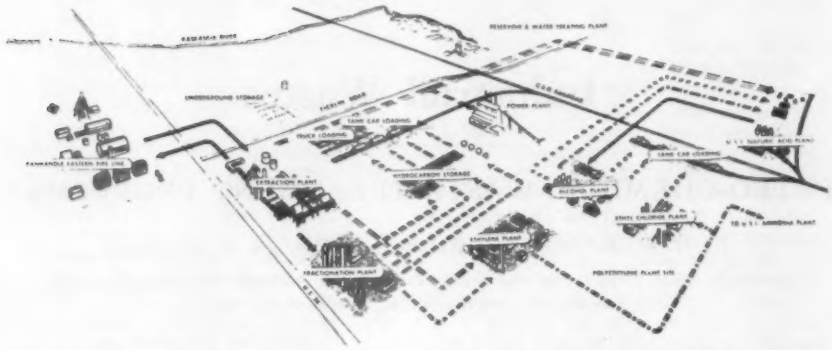

FIGURE 1.—Schematic layout of the National Petro-Chemicals Corp. facilities, Tuscola, Ill.†

into a reservoir 30 miles downstream.

After the start-up of facilities in 1953, it was found the combined waste stream contained 10 to 20 times more than the predicted amounts of B.O.D. material and several times the predicted quantity of acid. The extensive and often hurried efforts to cope with this effluent and avoid river pollution makes an interesting history.

Description of Wastes

The materials presently entering the petro-chemical plant effluent are of four general types: mineral acids, nitrogen compounds, oxidizable organic material and lubricating oils. The pH value of this effluent averages 2.3 and the conductivity measures more than 4,300 micro-ohms. The average amounts of these materials are:

SO_3—160 p.p.m.
SO_4—650 p.p.m.
Cl—190 p.p.m.
B.O.D.—150 p.p.m.
C.O.D.—260 p.p.m.

The amount of lubricating oil present is usually small, but collection is aggravated by some coke carry-over from the ethane cracking unit. The nitrates and nitrites have varied and are presently running very low.

† Courtesy *Power and Fluids.*

Evolution of Present Treatment

Initially the treatment facilities consisted of neutralization of the wastes with lime in a water clarifying unit. The clarified effluent was discharged to the river. A small Imhoff tank and trickling filter handled the sanitary wastes.

Excessive quantities of abrasive material in the wastes together with its low pH resulted in early failure of the bronze lift station pumps and cement asbestos piping used to convey wastes to the clarifier. Complete failure of the lift station meant that wastes entered the river untreated. In addition, the amounts of organic material discharged to the river without treatment during start-up operations resulted in a low dissolved oxygen content in the river.

In-Plant Control

Early in 1954, action was taken to build elaborate aeration basins and to chlorinate the effluent heavily. A new acid-brick lined lift station was built and acid-resistant pumps were installed. All cement-asbestos lines were replaced by tile and cast iron.

Extensive surveys of plant operations were made to determine where water and process drips and drains could be re-used or returned to the process. Facilities were installed for

hauling spent caustic and acid sludge from the plant. The acid sludge is stored in pits and slowly reworked. After investigating several disposal systems (including an abandoned mine), it was planned that the spent caustic would be trucked to a large river where the high dilution completely obscures it. In acid areas and neutralization pits, facilities were provided for the addition of lime and oil separator boxes installed as required.

Rinse water, from the regeneration of water demineralizers, and uneven waste flows from the process units resulted in shock loading of the neutralization facilities. In-plant cooling and settling basins of about 20 hr. retention time were built. These basins with a capacity of 2,000,000 gal. provide for the blending of the effluent streams and the skimming off of most of the floating oil.

Careful policing of in-plant wastes was initiated. This consisted of regular inspections by a committee plus daily analyses of waste streams from various units. The results of these improvements were to decrease the mineral acid load and allow a constant discharge of cooler, neutral waste. Unfortunately, the B.O.D. of the waste remained higher than could be tolerated by the river.

Filtration

Studies of biological oxidation of the waste using an existing 22-ft. trickling filter showed that an 80 per cent reduction in B.O.D. was possible at higher loadings than normally used when ammonium nitrate was added to stimulate biological growth. During the first test, the average B.O.D. loading was about 1.48 lb. per day per cubic yard of filter media and recirculation was not used. When a 2:1 recirculation to feed ratio was used, the average B.O.D. reduction was 90 per cent. The B.O.D. loading based on the waste flow was decreased to 0.97 lb. per day per cubic yard of filter media since the hydraulic loading was kept identical to that used in the first test. Effluent temperature averaged 90° F. during these tests, hence biological action was accelerated.

Oxidation Ponds

Biological oxidation of the waste in test ponds was also studied. These ponds were seeded with sanitary sewage and some sodium nitrate was added to stimulate algae growth. Neutralized effluent and neutralized, chlorinated and aerated effluent were studied. These tests showed a rapid decline in B.O.D. for about 8 days, after which the B.O.D. level stabilized at about 7 p.p.m. It was apparent that mechanical aeration and chlorination would not be necessary if proper biological action could be obtained.

Based on further confirmation of good biological oxidation of ponded effluent, full-scale ponds were constructed. These ponds (Figure 2) cover about 42 acres and consist of a series of 8 ponds of varying size. Total capacity is 55,000,000 gal. which is equivalent to approximately 18 days of retention time.

The ponds were put in service late in 1954, and operated at a low level to permit gravity flow to them if the lift station failed. After several months sufficient biological growth was produced to attain the excellent B.O.D. removal now experienced. The cold weather and short periods of daylight were probably the main reasons for the slow start.

The oxidation ponds were beginning to produce satisfactory results in early 1955. The B.O.D. reduction was about 50 per cent in early April, 1955 after four months of service. By May, 75 per cent of the B.O.D. was being removed. In June, 90 per cent of the B.O.D. was being removed resulting in an average effluent B.O.D. of 5 to 7 p.p.m. At present the B.O.D. removal is 90 to 95 per cent at a loading of about 75 lb. of B.O.D. per acre per

FIGURE 2.—Oxidation ponds for waste treatment (foreground) and the 100,000,000 gal. water supply reservoir. In the background is the Kaskaskia River flowing away from the oxidation ponds.

day. This is somewhat higher than the commonly used design value of 45 lb. of B.O.D. per acre per day, but will be reduced when the ponds are fully flooded. The D.O. content in the pond outfall is usually greater than that in the river.

By the middle of 1955 the petrochemical waste facilities were substantially completed and operating satisfactorily. Figure 3 shows schematically the facilities for both industrial and sanitary wastes. Some neutralization of the acid wastes is obtained with the waste lime sludge from the water treatment facilities.

Should the lift station pumps fail, the effluent must be able to flow by gravity to the oxidation ponds. Neutralization can be done at the agitated contact basin during this period. The present 24-in. tile line to the lift station was laid in an emergency and has such a high head loss that gravity flow to the oxidation ponds can be accomplished only with the ponds at a maximum of 60 per cent of their operating level. A new lift station, neutralization basin, and shorter sewer line are expected to be completed in October, 1955, to eliminate this problem and allow maximum use of the oxidation ponds. This will provide more waste treatment capacity and will improve contact of the waste effluent with the lime sludge and lime for better utilization of these materials. Lime will still be added to the neutralization clarifier for pH control to produce a settling floc.

River Conditions and Public Relations

Some of the pumping difficulties previously described resulted in unneutralized acid going to the river during the start-up period in 1953. This resulted in a fish kill which in most rivers would have been overlooked. However, the flow of the river was very low so the fish kill was quite evident. This alarmed people downstream so much that they began looking for minor changes in the stream which otherwise might have gone unnoticed. Difficulty in controlling the pH value of the river, followed by difficulties in keeping the D.O. content at a satisfactory level finally led to an injunction against National Petro-Chemicals Corp. At the time of the injunction, construction had already commenced on the in-plant cooling and settling basins to remove the shock load from the neutralization facilities. An aeration pit and large chlorinator were being installed.

By this time the corporation realized that it had not only a technical problem, but also a public relations problem. Many friends as well as critics did not realize the sums of money being spent in a sincere effort to have a clean river. The facilities were open for inspection by anyone interested, because National Petro-Chemicals Corp. was proud of its plant and what had been done. Every effort was made to be a good industrial citizen. Talks were presented at various civic clubs and many inspection trips of the manufacturing plant were arranged.

Many people knew that the plant was a major economic force in the area, but they did not fully realize how important. Others knew that the plant had caused dislocations, but did not realize that, in time, most of the dislocations would disappear and the plant would help bring about steadier employment in the area.

Continued efforts were made to study the technical aspects of the waste treatment problem. Accordingly, several consultants were retained to aid in planning a satisfactory solution. A survey of the Kaskaskia River by a stream biologist revealed that the river was not a biological desert, but that fish were abundant and were reproducing. The question of possible toxicity of the waste water was a source of worry to some critics. On the basis of the nature of the operations, it was impossible to believe that toxic substances were present in the waste. However, in order not to leave a stone unturned, a research program was sponsored at the Kettering Laboratory of the University of Cincinnati. The program has been in effect for over a year and to date, there are no indications of any toxic substance being present in the water. Since the start of plant operations two years ago, approximately $500,000 has been spent in improving the waste handling facilities.

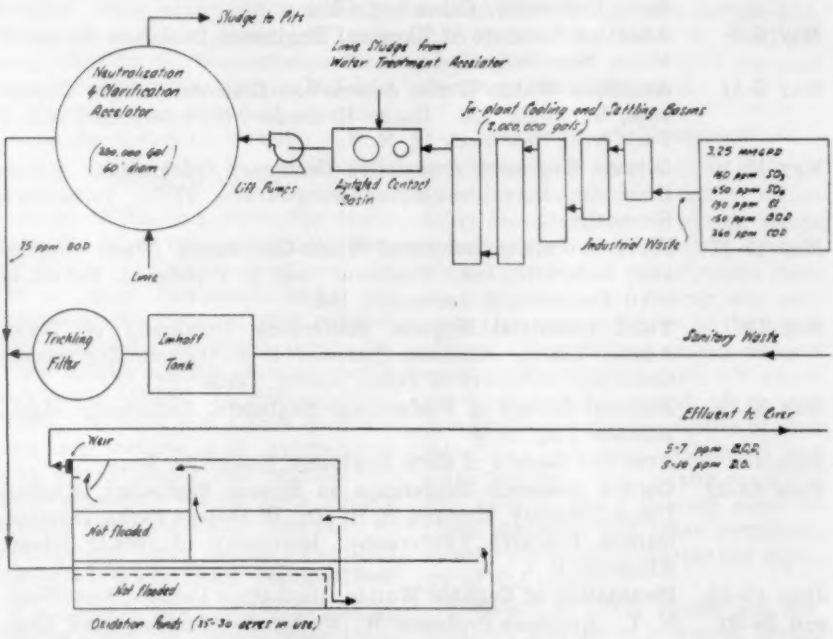

FIGURE 3.—Flow diagram of the petro-chemical waste treatment facilities, mid-1955.

Summary

A summary of experiences probably would be similar to those of many other companies:

1. The best treatment is elimination of the waste at the source. This elimination is never final because the slightest relaxation of attention can lead to new outbreaks.

2. Many phases of waste control pay off not only in improved public and legal relations, but also in actual dollars and cents savings.

3. Waste elimination must have the backing of every level of authority in the plant from the operator and the laboratory analyst to the top management.

The backing of top management and the hearty co-operation of all plant personnel involved has produced the now satisfactory conditions of waste treatment at this petro-chemical plant.

MEETINGS OF INTEREST

1956

Apr. 15–17	**Western Public Works Conference,** Oakland, Calif. General Chairman, John A. Morin, Engineer, Oakland, Calif.
Apr. 17–18	**Ninth Municipal and Sanitary Engineering Conference,** University of Florida, Gainesville, Fla. Dr. E. R. Hendrickson, College of Engineering, University of Florida, Gainesville, Fla. Conference theme—Atmospheric Pollution.
Apr. 21–27	**1956 Industrial Health Conference,** Philadelphia, Pa. The American Industrial Hygiene Assn.
May 4	**Annual Conference for Engineers,** College of Engineering, Ohio State University, Columbus, Ohio.
May 6–9	**American Institute of Chemical Engineers,** Louisiana Roosevelt Hotel, New Orleans, La.
May 6–11	**American Water Works Association Diamond Jubilee Conference,** St. Louis, Mo. Harry E. Jordan, Secretary, AWWA, 2 Park Ave., New York 16, N. Y.
May 12–15	**German Engineers Association Centenary Celebration.** Verein Deutscher Ingenieure Prinz-Georg-Strasse 77/79, Dusseldorf, Germany.
May 15–17	**Eleventh Purdue Industrial Waste Conference,** Purdue University, Lafayette, Ind. Professor Don E. Bloodgood, School of Civil Engineering, Lafayette, Ind.
May 19	**Third Industrial Hygiene Conference,** University of Texas, Austin, Texas. Associate Professor E. F. Gloyna, Engineering Building, University of Texas, Austin, Texas.
May 23–26	**National Society of Professional Engineers,** Ambassador Hotel, Atlantic City, N. J.
June 4–8	**American Society of Civil Engineers,** Knoxville, Tenn.
June 18–22	**Gordon Research Conference on Stream Sanitation,** Kimball Union Academy, Meriden, N. H. Dr. W. George Parks, Director, Gordon Research Conferences, University of Rhode Island, Kingston, R. I.
June 18–23, and 25–30	**Bioxidation of Organic Wastes,** Manhattan College, New York, N. Y. Assistant Professor W. Wesley Eckenfelder, Civil Engineering Dept., Manhattan College, New York 71, N. Y.

PRETREATMENT OF METAL-FINISHING WASTES AT RALEIGH, NORTH CAROLINA *

By J. M. Roberts

Consulting Engineer, Robert and Company Associates, Atlanta, Ga.

With the rapid expansion of industry in the South and the growing demand for more automatic and electronically operated equipment there is certain to be an increase in metal finishing and electronic equipment manufacture throughout the Southland. These industries will bring with them the problems of disposing of metal finishing wastes. Although these problems are relatively new to the South, there is a wealth of experience to draw on. It will be the responsibility of consulting engineers and operating personnel to use this knowledge to solve the problems that will be confronted. This paper will specifically discuss the metal-finishing waste treatment plant for the Westinghouse Electric Manufacturing Co. at Raleigh, N. C. which was placed in operation during the spring of 1954.

Source of Waste

In metal finishing plants the waste generally comes from stripping, cleaning and metal plating operations. In the stripping operations, which are essentially the cleaning, rust removal and refinishing of metal parts, the waste usually consists of strong acids and strong alkalis. In cleaning operations, the acids and alkalis normally used are sulfuric acid, hydrochloric acid, strong alkalis and patented organic cleaners. Wastes from plating usually contain metallic ions such as cyanide and heavy metals. The total industrial waste load results from dumping spent rinses, spent cleaning liquors and plating baths together with losses from these processes. These losses are from spill-over, wastage, drag-out of the solution and similar operations.

At the Raleigh Westinghouse Plant the processes use nickel, cadmium, tin and "bright alloy" which is an alloy of copper, zinc and tin. The particular operations considered are concerned with cleaning and plating the metal. Other processes produce the chromate finish on aluminum and the phosphate finish on iron. The plant manufactures watt-hour meters and sockets and operates on a normal two-shift basis. The waste is relatively small in volume; however, it contains some very toxic substances.

Necessity of Treatment

Substances of such toxicity will require treatment or removal before being discharged into receiving bodies of water or a public sewer system. Strong acid wastes will of course damage and eventually destroy any concrete pipe that might be in the sewer system. They will act on any exposed mortar in the manholes and will attack anything made of cement. It is true that alkalis are also destructive of such materials. Cleaning solutions and soaps that will produce fatty acids also will form a sticky floating scum on pipes, manholes and other structures, thereby eventually reducing the capacity of the system.

Solutions of heavy metals and cyanide will also affect biological sewage treatment processes. Most authorities

* Presented at 1955 Annual Meeting, North Carolina Sewage and Industrial Waste Assn.; Winston Salem, N. C.; Nov. 14–16, 1955.

agree that a sewage containing 5 p.p.m. of chromium will kill the biological growth on a trickling filter. Cyanide will decrease the efficiency of a filter; however, some bacteria seem to eventually become acclimated to cyanide and biological processes have been known to recover. If the cyanide concentration varies excessively there is a good possibility of the filter being inoperative at least part of the time. Nickel is extremely toxic and only a few p.p.m. will destroy activated sludge as well as trickling filter flora. In some instances, small quantities of metals have apparently had a beneficial effect on digestion but the limit is very critical.

Design Requirements

The meter manufacturing plant at Raleigh was expected to have a continuous flow of 40 g.p.m. of cyanide waste and 160 g.p.m. of other wastes essentially acid-alkali wastes, based on a 16-hr. manufacturing operation. The city of Raleigh had set up definite requirements for receiving industrial waste effluents. These were established to prevent damage to the sewage treatment plant proposed by the city for construction in the Crabtree Creek drainage area. A tabulation of these requirements is given in Table I.

Nickel and cyanide are the two elements in the Westinghouse waste requiring removal to meet the city of Raleigh requirements. By reducing the nickel concentration to 0.1 p.p.m. the other heavy metals would be reduced accordingly. The complete destruction of cyanide also would be required. On this basis the waste treatment plant essentially becomes a facility to remove nickel and cyanide. Of course, the adjustment of acid and alkaline solutions will be necessary in order to accomplish this.

TABLE I.—Concentrations of Industrial Wastes

Waste	Concentration of Toxic Components (p.p.m.)	
	Westinghouse Raw Wastes	City of Raleigh Requirements
Cyanide	5.3	0.1[1]
Zinc	2.5	5
Cadmium	1.5	5
Tin	3.1	5
Nickel	3.1	0.1
Chromium	1.5	5
Iron	0.3	5
Copper	0.6	5
pH	—	7+

[1] Occasionally only.

Pretreatment Process

Treatment of these wastes required a complete separation of acid-alkali waste from the cyanide waste. This was taken into consideration during the design of the manufacturing plant. The industrial waste sewer system was arranged so that all waste would be delivered to the waste treatment plant through two sewers. One sewer would convey the acid-alkali wastes and the other would bring the cyanide waste.

In order to keep acids from damaging any part of the treatment system, the wastes are normally neutralized at the treatment plant to a pH between 8 and 9. This is sometimes done on a flow-through basis utilizing automatic lime feeding equipment. Occasionally when it is necessary to dump large quantities of acid, additional lime is added manually to supplement the automatic equipment. The operator of the plating room does attempt to dump acid and alkali waste at the same time in order to effect some neutralization to conserve chemicals at the waste treatment plant. After adjustment to this pH value, ferrous sulfate is fed to precipitate the metals either as hydroxides or carbonates in an alkaline solution.

The cyanide wastes are destroyed by chlorination in an alkaline solution. This method of destroying cyanides has been successfully used in recent years, and is generally accepted as an economical method. In most treatment plants the reaction is operated as

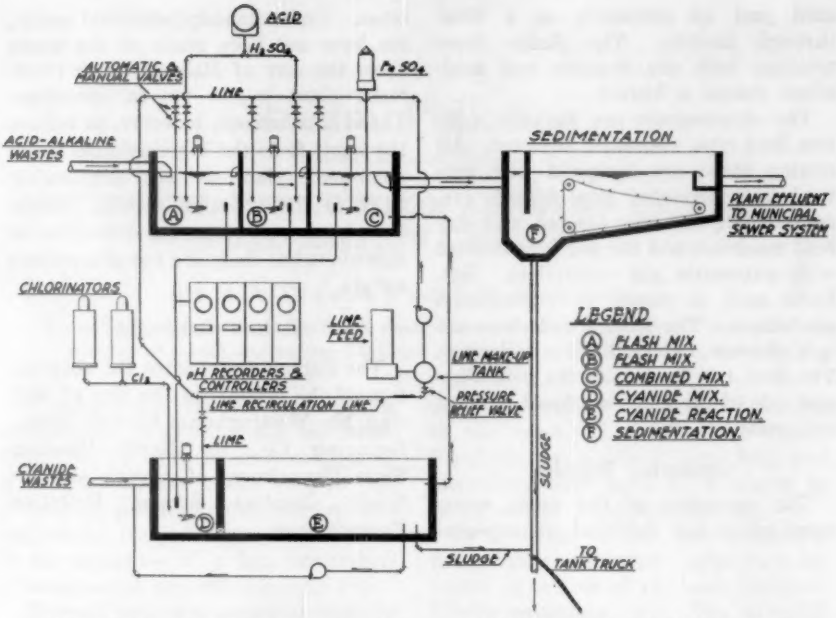

FIGURE 1.—Schematic diagram of the metal finishing waste treatment plant, Westinghouse Electric Manufacturing Co., Raleigh, N. C.

a batch process; however, this new treatment facility may be operated either as a batch or a flow-through process.

This treatment of the cyanide waste results in a salty solution and the release of carbon dioxide and nitrogen. Completion of the reaction takes at least one hour in the presence of an excess of chlorine.

The treatment facilities are divided into two separate units (Figure 1); one for treating acid-alkali wastes, the other for cyanide wastes. On the acid-alkali side of the treatment plant the first mixer is a buffer mixer where the pH value of the waste is partially adjusted by the addition of lime. In the following basin the pH is adjusted to its final value of approximately 8.5. In the third basin the waste is mixed with the treated cyanide waste and ferrous sulfate is added. Finally, the combined wastes are settled, the sludge is removed and the overflow discharges to the sewer leading to the proposed Raleigh treatment plant.

On the cyanide side of the waste treatment plant, at the flash mixer, chlorine and lime are added to obtain a pH value of approximately 8.5. In this basin the cyanates are formed. The solution now is circulated in the next basin by the recirculating pump in the presence of an excess of chlorine. When the treatment plant is operated as a flow-through facility this circulation results in a turnover of probably 4 or 5 times. It is necessary to adjust the chlorinators so that there will always be an excess of chlorine regardless of the flow into the treatment plant. At the present time the cyanide waste is being treated in a batch type operation since the only cyanides coming to the treatment plant are received when a bath is dumped. There is sufficient storage in the meter manufacturing plant to permit operating the treatment plant on a batch type basis. However, it can be oper-

ated just as efficiently as a flow-through facility. The sludge from treating both the cyanide and acid-alkali wastes is buried.

The chlorinators are vacuum solution feed type, manually adjusted. All mixing tanks are equipped with vertical-shaft propeller type mixers, ferrous sulfate and lime are fed with dry feed machines and the pH is controlled with automatic pH controllers. Sulfuric acid is stored in rubberlined containers. The sludge collectors are straight-line drag-flight collectors. The first two basins on the acid-alkaline side of the plant are lined with an acid-resistant lining.

Operating Results

The operation of the waste treatment plant has fullfilled all expectations. Unfortunately, chemical analyses have not been made of the waste since the city of Raleigh waste treatment plant is not yet in operation. There is no reason, however, to believe the waste from the Westinghouse waste treatment plant is not conforming fully to the expected results. There have been some operating difficulties in this plant but these are not of a serious nature.

Acknowledgment

The author appreciates the cooperation of the officials of the city of Raleigh, the Westinghouse Electric Manufacturing Co., the North Carolina State Department of Health and the North Carolina Stream Pollution Committee.

M.I.T. SUMMER COURSES

Recent advances in biochemical processing of industrial wastes will be reviewed during a two-week special summer program, August 20–31, 1956, at Massachusetts Institute of Technology.

The program is planned primarily for chemical engineers, sanitary engineers, and chemists who seek a better understanding of the role of biochemistry, both fundamental and applied, in the processing of organic chemical wastes. The presentation of principles will lay the groundwork for application to virtually any type of industry. Lectures and demonstrations will cover the following topics: principles of microbiology and biochemistry of microorganisms, characterization of wastes by analytical chemical methods, stream pollution, aerobic and anaerobic biological treatment, sludge concentration and disposal, and pilot-plant design and operation.

Registration fee is $200 and living accommodations are available in the Institute's dormitories. All M.I.T. recreational facilities are available for use.

Complete information and application blanks may be obtained from the Summer Session Office, Room 7–103, Massachusetts Institute of Technology, Cambridge 39, Mass.

Stream Pollution

STATISTICAL METHOD FOR ANALYSIS OF STREAM PURIFICATION CAPACITY *

By M. A. Churchill and R. A. Buckingham

Respectively, Chief, Stream Pollution Control Section, and Public Health Engineer, Division of Health and Safety, Tennessee Valley Authority, Chattanooga, Tenn.

A method has been developed by the authors for predicting the maximum reduction in oxygen concentration in a polluted stream under various conditions of pollution load, stream flow and water temperature. This method is an expansion of a less comprehensive approach presented earlier (1).

Streams have a tremendous capacity for self-purification, and economy dictates that as much—but no more—of a stream's natural capacity for absorbing pollution should be used as is consistent with all other downstream uses of the water. After determining the extent of natural purification a stream can supply, while still maintaining water of a quality suitable for the other uses, the extent of waste treatment needed to handle the excess load is quite apparent. A new method for determining a stream's purification capacity is presented.

Limitations of Methods

While a number of previous investigators have developed methods for determining the relationship of dissolved oxygen to pollution loads in a stream, there are certain objections to the existing methods. One of the most serious objections is the cost of determining the time of flow of water from sampling station to sampling station in the reach of river under study. Furthermore, a fairly large field and laboratory staff must be available to carry on the intensive surveys.

In addition to the cost considerations, there are other difficulties involved in the use of the basic Streeter-Phelps equations (2). The so-called constants k_1 and k_2 are determined from an intensive survey, usually at a fairly low, steady, stream flow. However, if another survey is made on the same reach, even fairly soon after the first one, it at once becomes obvious that the "constants" may vary considerably from the values first determined. This situation has been known for some time but it is brought out quite strikingly again in a recent report on the upper Potomac River (3). The real use of any method of analysis is its application to conditions of load, flow, and temperature, other than those actually measured. When the derived "constants" are far from constant, the results of computations involving these "constants" for other conditions of load, flow, and temperature, are certainly open to question.

The method of analysis proposed herein is based on the multiple correlation of all the principal factors producing and controlling the extent of the dissolved oxygen (D.O.) sag below a source of pollution. The earlier paper (1) correlated the extent of the

* Presented at 1955 Annual Meeting, Kentucky-Tennessee Industrial Wastes and Sewage Works Assn.; Lexington, Ky.; Sept. 12–14, 1955.

D.O. sag with the B.O.D. load. The present paper correlates the extent of the D.O. sag not only with the B.O.D. but also with water temperature and stream discharge. Time of water travel determinations are not necessary. Long-term B.O.D. determinations are not required since the B.O.D. constants k_1 and L are not used in the analysis. Office computations are fairly simple although to one unfamiliar with statistical procedures they may at first appear rather complicated.

Pollution from a Single Source

The following discussion is concerned principally with a stream that is polluted from a single source. Degradation and recovery follow a natural course, uncomplicated by other downstream pollution. The basic method of analysis developed for this situation can be applied to many locations with little, if any, modification.

A short discussion is included concerning a situation downstream from an impoundment. Here a deficit in oxygen exists in the water discharged through low outlets in the dam. Municipal and industrial pollution are discharged into this water, already oxygen-deficient, at a location only a short distance downstream from the dam. This type of situation is becoming more common as river-control projects are completed in the United States and other countries. The basic method of analysis is the same for both situations but the second method requires inclusion of the additional variable, initial D.O. deficit.

Basic Theory

A number of factors operate concurrently to produce a D.O. deficiency in a stream below a source of pollution. The basic procedure discussed here correlates these factors statistically, all at the same time, with the measured decrease, or drop, in D.O. concentration from above the point of pollution to the low point of the D.O. sag. The factors used must be readily measurable in quantitative units.

In the normal pollution situation the river upstream from the pollution source under study contains water reasonably well saturated with oxygen. When pollution is discharged into a stream such as this the factors subject to direct quantitative observation which affect the extent of the D.O. sag are the B.O.D., stream temperature and stream discharge. Time of water travel is intentionally omitted for the reasons given previously. Actually, water travel effects are indirectly included, because discharge is included in the correlation, and time of travel is obviously correlated with discharge.

If the above factors are the controlling ones, and the authors believe they are, then a statistical correlation of observed values of the so-called independent variables, with corresponding observed values of the dependent variable, D.O. drop, should result in an equation that can be used with confidence to predict the extent of the D.O. drop for various assumed values of the independent variables. The simplest type of multiple correlation relationship is expressed by the linear equation:

$$Y = a + b_1X_1 + b_2X_2 + b_3X_3 \quad (1a)$$

in which

Y = the dependent variable, D.O. drop, in p.p.m.
X_1 = 5-day B.O.D. in p.p.m.
X_2 = water temperature in °C.
X_3 = stream discharge factor
a, b_1, b_2, b_3 = constants derived from the data actually used.

FIGURE 1.—Location of sampling stations in example illustrated.

The procedure involved can be best illustrated by following the development from an actual set of observed data.

Prediction Equations for a Specific Case

The observed data on which the main part of this paper is based were supplied by an actual industry in the Tennessee Valley, hereinafter referred to as "Industrial Plant." The data illustrate the type of information any progressive industry can obtain with reasonable cost concerning the effects of its wastes on the receiving streams.

Industrial Plant draws its process water from "Plant River" and also discharges its wastes back into the same stream. A short distance downstream Plant River flows into "Main River" (Figure 1).

Basic Data

Technical personnel of Industrial Plant collected field data and water samples routinely from a number of sampling stations on Plant River, Branch River, and Main River. The stations are located as shown in Figure 1. Stream discharges, based on records from three gaging stations on the Main River and from gaging stations on five local tributaries, were supplied by the Hydraulic Data Branch, Tennessee Valley Authority.

The mill is located on Plant River, a small tributary of Main River. Above the mill Plant River contains practically no pollution, as the stream flows out of a sparsely inhabited area.

The samples collected are truly random, according to mill officials, and were taken to indicate the pollutional effect of mill operations on the waste-receiving stream. The normal operation of the mill results in variable loadings on the stream on an hour-to-hour and day-to-day basis.

The results of B.O.D. grab samples, showed the maximum observed load on Plant River below the mill to be at the rate of 62,800 lb. per day, and the minimum 9,600 lb. per day. Obviously, the results of grab samples must be interpreted carefully in order not to be misleading. With the aid of statistical procedures, however, the grab sample values can yield dependable results when analyzed by the method proposed herein.

Effect on D.O. in Main River

Figure 2 shows the effects of the pollution load on D.O. concentrations downstream from the junction of Plant River and Main River. The D.O. curve profiles were drawn in between stations. (Extreme care should be exercised in drawing these profiles. As explained later, accuracy will be improved if a sampling station can be located as near as possible to the usual location of the low point of the D.O. sag curve at low flow.)

The B.O.D. load in the Main River above the mouth of the Plant River is very low. The only sizable organic load imposed on the Main River in the 30-mile reach below the mouth of the Plant River is that from the mill.

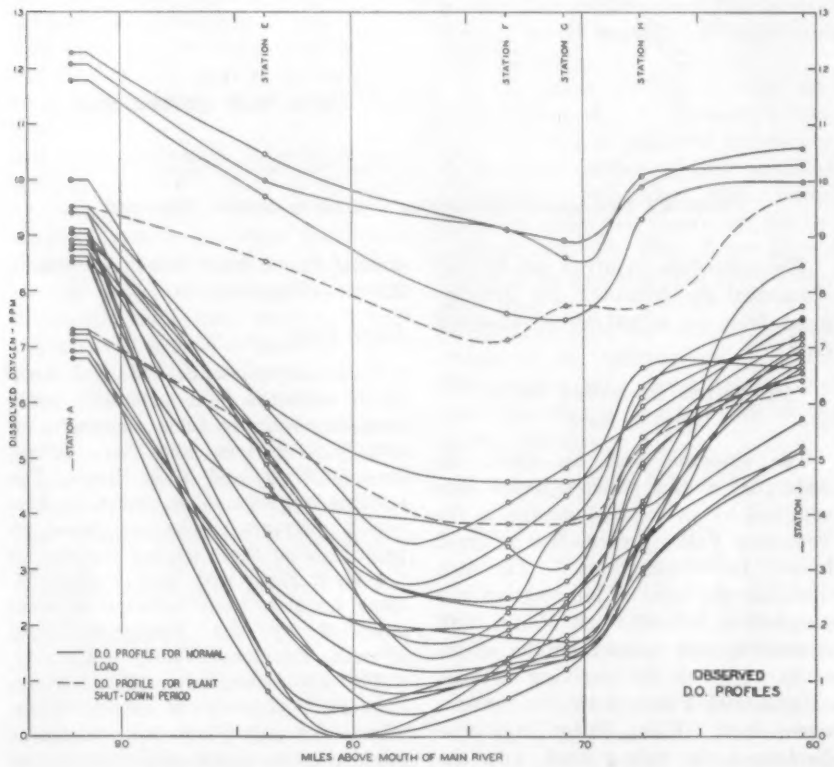

FIGURE 2.—Observed D.O. profiles on Main River.

TABLE I.—Multiple Linear Correlation of D.O. Drop, B.O.D., Temperature, and Discharge Station A to D.O. Sag

Date	D.O. Drop A to D.O. Sag (p.p.m.) Y	B.O.D. at Stat. F (p.p.m.) X_1	Temp. (°C.) X_2	$\frac{10,000}{\text{c.f.s.}}$ X_3	Y^2	YX_1	YX_2	YX_3	X_1^2	X_1X_2	X_1X_3	X_2^2	X_2X_3	X_3^2
6/19/44	6.5	3	23.1	15.36	42.25	19.50	150.15	99.84	9.00	69.30	46.08	533.61	354.82	235.93
6/23	5.7	6	21.6	17.76	32.49	34.20	123.12	101.23	36.00	129.60	106.56	466.56	383.62	315.42
7/1	7.4	7	21.1	18.94	54.76	51.80	156.14	140.16	49.00	147.70	132.58	445.21	399.63	358.72
7/5	2.4	2	18.5	19.42	5.76	4.80	44.40	46.61	4.00	37.00	38.84	342.25	359.27	377.14
7/15	6.3	5	21.1	13.95	39.69	31.50	132.93	87.88	25.00	105.50	69.75	445.21	294.34	194.60
7/22	7.0	7	20.3	20.00	49.00	49.00	142.10	140.00	49.00	142.10	140.00	412.09	406.00	400.00
7/26	7.4	7	22.0	24.88	54.76	51.80	162.80	184.11	49.00	154.00	174.16	484.00	547.36	619.01
7/27	8.1	7	22.3	25.45	65.61	56.70	180.63	206.14	49.00	156.10	178.15	497.29	567.54	647.70
7/28	8·1	9	23.3	26.39	65.61	72.90	188.73	213.76	81.00	209.70	237.51	542.89	614.89	696.43
7/29	8.9	7	22.6	24.21	79.21	62.30	201.14	215.47	49.00	158.20	169.47	510.76	547.15	586.12
8/2	6.0	4	20.0	10.45	36.00	24.00	120.00	62.70	16.00	80.00	41.80	400.00	209.00	109.20
8/19	9.0	10	21.8	23.42	81.00	90.00	196.20	210.78	100.00	218.00	234.20	475.24	510.56	548.50
8/26	7.3	9	20.2	29.41	53.29	65.70	147.46	214.69	81.00	181.80	264.69	408.04	594.08	864.95
9/2	6.0	7	22.2	19.01	36.00	42.00	133.20	114.06	49.00	155.40	133.07	492.84	422.02	361.38
9/20	5.7	7	19.5	19.92	32.49	39.90	111.15	113.54	49.00	136.50	139.44	380.25	388.44	396.81
10/18	7.2	9	12.0	28.09	51.84	64.80	86.40	202.25	81.00	108.00	252.81	144.00	337.08	789.05
10/30	7.6	11	10.5	32.26	57.76	83.60	79.80	245.18	121.00	115.50	354.86	110.25	338.73	1,040.71
12/5	3.4	11	2.5	16.95	11.56	37.40	8.50	57.63	121.00	27.50	186.45	6.25	42.38	287.30
12/21	3.6	7	2.0	18.42	12.96	25.20	7.20	66.31	49.00	14.00	128.94	4.00	36.84	339.30
1/26/45	4.3	7	5.0	16.95	18.49	30.10	21.50	72.88	49.00	35.00	118.65	25.00	84.75	287.30
3/20	4.2	5	15.5	12.90	17.64	21.00	65.10	54.18	25.00	77.50	64.50	240.25	199.95	166.41
5/31	5.5	6	20.0	15.15	30.25	33.00	110.00	83.32	36.00	120.00	90.90	400.00	303.00	229.52
6/13	6.2	4	22.0	20.49	38.44	24.80	136.40	127.04	16.00	88.00	81.96	484.00	450.78	419.84
7/5	3.5	2	21.5	20.00	12.25	7.00	75.25	70.00	4.00	43.00	40.00	462.25	430.00	400.00
Sums	147.3	159.0	430.6	489.78	979.11	1,023.00	2,780.30	3,129.76	1,197.00	2,709.40	3,425.37	8,712.24	8,822.23	10,671.34
Means	6.13750 M_Y	6.62500 M_1	17.94167 M_2	20.40750 M_3										
Correction Items* (nM_Y^2, nM_YM_1, nM_YM_2, etc.)					904.05	975.86	2,642.81	3,006.02	1,053.38	2,852.73	3,244.79	7,725.68	8,787.47	9,995.19
Corrected Sums					75.06	47.14	137.49	123.74	143.62	−143.33	180.58	986.56	34.76	676.15

* n = number of observations = 24.

Correlation of Variables

In the multiple linear correlation of variables it is necesary to compute the sums of squares of deviations of each variable from its own mean value, and also to compute the sums of cross products of deviations. Table I shows how these values are computed and tabulated.

In Table I, values of B.O.D., temperature and discharge used are as observed at Station F. Values of these variables as observed at Station E, also located near the low point of the D.O. sag, could have been used but in this particular situation a slightly better correlation (higher correlation coefficient) was obtained using Station F data. The B.O.D. of samples collected from a station, such as F, on the D.O. sag obviously indicate the concentration of pollution remaining in the water at that location. If the B.O.D. is high here then it must have been still higher at the source. Since good mixing in the river has occurred by the time the water reaches Station F, better results are obtained by using the B.O.D. as measured at this station rather than at a station just below the source, where accurate sampling is exceedingly difficult.

Values of D.O. drop shown in Table I, Column 2, were obtained by subtracting the D.O. value at the low point of the profile, Figure 2, from the observed D.O. value on the same profile at Station A, above pollution. In the heading of Column 5, Table I, the discharge at Station F is shown in the denominator for reasons that will be explained later. The number, 10,000, in the numerator of the heading for Column 5 was selected merely to give values of convenient size for the resulting quotients. The actual value of this number is not important since it is an arbitrary constant. The other column headings are self explanatory.

At the bottom of Table I the values following the words "Correction Item" are simply values obtained as indicated that yield upon subtraction, of the sums of squares of deviations and sums of cross products of deviations that are necessary for further computations.

Values in Basic Equation

Returning to the basic form of the linear equation, Eq. 1a, and substituting therein:

$$\text{D.O. drop} = a + b_1(\text{B.O.D.}) + b_2(\text{temp.}) + b_3\left(\frac{10{,}000}{\text{c.f.s.}}\right) \quad (1b)$$

an equation is obtained in which it is desired to evaluate the a constant and the three b constants.

If deviations from the means of each of the variables are used, instead of the observed values directly, the basic equation can be written:

$$y = b_1x_1 + b_2x_2 + b_3x_3 \quad (2)$$

Following the principles of least squares it is desired to minimize:

$$\Sigma(y - b_1x_1 - b_2x_2 - b_3x_3)^2 \quad (3)$$

Using standard mathematical procedures for doing this, the following three "normal" equations result:

$$b_1\Sigma x_1^2 + b_2\Sigma x_1x_2 + b_3\Sigma x_1x_3 = \Sigma x_1y \quad (4a)$$

$$b_1\Sigma x_1x_2 + b_2\Sigma x_2^2 + b_3\Sigma x_2x_3 = \Sigma x_2y \quad (5a)$$

$$b_1\Sigma x_1x_3 + b_2\Sigma x_2x_3 + b_3\Sigma x_3^2 = \Sigma x_3y \quad (6a)$$

Now, by substituting values from the bottom row in Table I into the appropriate locations in the three normal equations, and solving these equations simultaneously, by a technique known as the Doolittle Method, values of the three b constants in the basic equation are determined.

Determination of Values of b constants in Basic Equation

	$143.62b_1-$	$143.33b_2+$	$180.58b_3 =$	$+47.14$	(4b)
Dividing Eq. 4b by -143.62 then	$-b_1+0.997981b_2-$	$1.257346b_3 =$	-0.328227	(4c)	
and	$-143.33b_1+$	$986.56b_2+$	$34.76b_3 =$	$+137.49$	(5b)
Multiplying Eq. 4b by $+0.997981$	$+143.33b_1-$	$143.04b_2+$	$180.22b_3 =$	$+47.04$	(10)
(Σ_2)		$+ 843.52b_2+$	$214.98b_3 =$	$+184.53$	
Dividing (Σ_2) by -843.52		$-b_2-0.254861b_3 =$		-0.218762	(5c)
	$180.58b_1+$	$34.76b_2+$	$676.15b_3 =$	$+123.74$	(6b)
Multiplying Eq. 4b by -1.257346	$-180.58b_1+$	$180.22b_2-$	$227.05b_3 =$	-59.27	(13)
Now, multiplying (Σ_2) by -0.254861		$- 214.98b_2-$	$54.79b_3 =$	-47.03	(14)
(Σ_3)			$+ 394.31b_3 =$	$+17.44$	
			$b_3 =$	$+0.0442$	

Substitute in Eq. 5c:

$-b_2-0.011265 = -0.218762$ $\quad b_2 = +0.2075$

Substitute in Eq. 4c:

$-b_1+0.207081-0.055575 = -0.328227$ $\quad b_1 = +0.4797$

Check in Eq. 6b:

$86.624+7.213+29.886$ should $= 123.74$
$123.723 = 123.74$

$a = M_Y-b_1M_1-b_2M_2-b_3M_3$
$a = 6.1375-3.1780-3.7229-0.9020$ $\quad a = -1.6654$

In equations such as Eq. 4b it is necessary to carry the calculations to five or six decimal places in order to obtain a check when the derived values are substituted back in Eq. 6b Otherwise, the values will not check in this equation and yet there may be no actual error in the computations.

It will be noted that the a constant is determined, as shown at the end of the above computations, from the mean values of the four variables and from the b values just determined. The final equation can now be written as:

$$\text{D.O. drop, in p.p.m.} = -1.665 + 0.480(\text{B.O.D.}) + 0.208(\text{temp.}) + 0.044\left(\frac{10{,}000}{\text{c.f.s.}}\right)$$

This equation is the one that will produce the most accurate prediction possible from the available data if a linear equation is to be used in the form given. This is true since the principles of least squares yield an equation such that the sum of the squares of the deviations of the observed values, from the values computed by the formula, is a minimum.

By inserting any reasonable (i.e., not too far beyond the observed range) values of the independent variables in the final equation, the corresponding D.O. drop from Station A to the low point of the D.O. sag will result.

The data presented in Table II, show the results of computations with

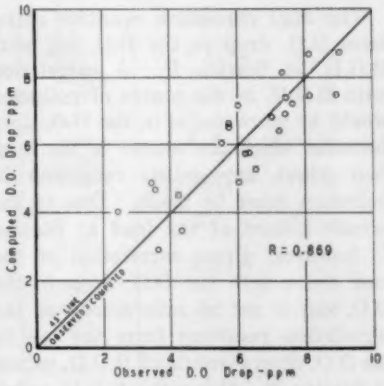

FIGURE 3.—D.O. drop from above pollution to D.O. sag—observed *vs.* computed values.

TABLE II.—Computation of D.O. Drop Values Corresponding to Observed Values

Date	Observed D.O. Drop (p.p.m.)	+0.480 × B.O.D.	+0.208 × Temp.	$+0.044 \times \left(\frac{10{,}000}{\text{c.f.s.}}\right)$	Computed D.O. Drop (p.p.m.)
6/19/44	6.5	1.44	4.80	0.68	5.25
6/23	5.7	2.88	4.49	0.78	6.48
7/1	7.4	3.36	4.39	0.83	6.91
7/5	2.4	0.96	3.85	0.85	3.99
7/15	6.3	2.40	4.39	0.61	5.73
7/22	7.0	3.36	4.22	0.88	6.79
7/26	7.4	3.36	4.58	1.09	7.36
7/27	8.1	3.36	4.64	1.12	7.45
7/28	8.1	4.32	4.85	1.16	8.66
7/29	8.9	3.36	4.70	1.07	7.46
8/2	6.0	1.92	4.16	0.46	4.87
8/19	9.0	4.80	4.53	1.03	8.69
8/26	7.3	4.32	4.20	1.29	8.14
9/2	6.0	3.36	4.62	0.84	7.15
9/20	5.7	3.36	4.06	0.88	6.63
10/18	7.2	4.32	2.50	1.24	6.39
10/30	7.6	5.28	2.18	1.42	7.21
12/5	3.4	5.28	0.52	0.75	4.88
12/21	3.6	3.36	0.42	0.81	2.92
1/26/45	4.3	3.36	1.04	0.75	3.48
3/20	4.2	2.40	3.22	0.57	4.52
5/31	5.5	2.88	4.16	0.67	6.04
6/13	6.2	1.92	4.58	0.90	5.73
7/5	3.5	0.96	4.47	0.88	4.64

the formula for each set of observed values. Figure 3 gives a graphical comparison of observed values versus computed D.O. drop values as listed in Columns 2 and 6 of Table II.

Progressive Downstream Reduction in B.O.D. Load

The final regression equation correlates D.O. drop to the D.O. sag with B.O.D. at Station F. A correlation with B.O.D. at the source of pollution would be more useful in the D.O. drop formula, since the source is the location where any actual reduction in pollution must be made. Due to the erratic nature of the load at Station C, however, direct correlation of the load there with the D.O. drop to the D.O. sag is not as satisfactory as the correlation resulting from the use in the D.O. drop formula of B.O.D. values at Station F. Using the B.O.D. value at Station F, it is necessary to correlate the B.O.D. load as measured there with the B.O.D. load at the source of pollution. For that purpose, a multiple correlation method is given in Table III. A second method for making this correlation is based on the simple assumption that the progressive downstream reduction in B.O.D. load described by the mean observed B.O.D. loads at the various stations will maintain these same relative values as the B.O.D. load at the source is reduced by treatment of the waste at the source.

Although the multiple correlation procedure for computing the B.O.D. load at Station F will yield (in most cases) more accurate results, the method of proportions is much simpler to use and gives results fairly close to those obtained by the correlation procedure for the range considered.

The B.O.D. load at a downstream station, such as F, near the low point of the D.O. sag curve is reasoned to be a function of: (a) the load put into the river plus the natural B.O.D.

load; (b) the stream temperature, and (c) the stream discharge. (Note that the time of water travel is not necessary, since the time correlates with discharge.) Therefore, the equation for the B.O.D. load at a station, such as F, can be written:

B.O.D. load at Station F
$= a + b_1$(Load at Stations A+C)
$+ b_2$(Temp. at Station F)
$+ b_3$(Discharge at Station F) (7a)

The observed values of the several variables used, and a summary of the computations, for deriving the constants in Eq. 7a are shown in Table III. The completed equation is:

B.O.D. load at Station F
$= 12.086 + 0.179$(Load at Stations A+C) $- 0.394$(Temp. at Station F)
$+ 1.197$(Discharge at Station F) (7b)

In this equation B.O.D. loads are expressed in 1,000 lb. per day, temperature in degrees Centigrade, and discharge in 100 c.f.s. By inserting selected values of the independent variables in the equation (7b), the resulting B.O.D. load at Station F can be readily computed. For the particular case discussed here, considering the intermittent nature of the added B.O.D. loads from Industrial Plant, a fairly high coefficient of multiple correlation is determined for this

TABLE III.—Multiple Linear Correlation of B.O.D. Loads, Temperature, and Discharge Source of Pollution to Station F

Date	B.O.D. (1,000 lb. per day) at Stat. F	B.O.D. (1,000 lb. per day) at Stat. A+C	Temp. at Stat. F °C.	Disch. at Stat. F 100 c.f.s.	Remarks
	Y	X_1	X_2	X_3	
6/19/44	10.5	49.1	23.1	6.51	
6/23	18.2	43.4	21.6	5.63	
7/1	20.0	61.7	21.1	5.28	
7/5	5.6	4.1	18.5	5.15	Corrected Sums for:
7/15	19.4	21.9	21.1	7.17	
7/22	18.9	55.3	20.3	5.00	Y^2 = 828.91
7/26	15.2	34.5	22.0	4.02	
7/27	14.9	48.7	22.3	3.93	YX_1 = 1246.20
7/28	18.4	12.4	23.3	3.79	
7/29	15.6	54.4	22.6	4.13	YX_2 = − 466.62
8/2	20.7	23.5	20.0	9.57	
8/19	23.1	44.8	21.8	4.27	YX_3 = 45.71
8/26	16.5	35.5	20.2	3.40	
9/2	19.9	53.3	22.2	5.26	X_1^2 = 6930.93
9/20	19.0	30.6	19.5	5.02	
10/18	17.3	43.1	12.0	3.56	X_1X_2 = − 361.93
10/30	18.4	49.1	10.5	3.10	
12/5	35.0	67.8	2.5	5.90	X_1X_3 = − 114.85
12/21	20.5	22.8	2.0	5.43	
					X_2^2 = 986.56
1/26/45	22.3	37.1	5.0	5.90	
3/20	20.9	28.2	15.5	7.75	X_2X_3 = − 10.75
5/31	21.4	23.4	20.0	6.60	
6/13	10.5	24.8	22.0	4.88	X_3^2 = 51.83
7/5	5.4	3.2	21.5	5.00	
Sums	427.6	872.6	430.6	126.25	
Means	17.81667 M_Y	36.35833 M_1	17.94167 M_2	5.26042 M_3	Number of observations = 24.

equation. In those situations where the B.O.D. load is not so abruptly variable with time, a higher coefficient of multiple correlation should be obtained.

Figure 4 is a plot of observed B.O.D. loads at Station F versus B.O.D. loads computed for this location by the multiple regression B.O.D. load reduction formula. Reasonably good agreement is indicated.

A second method of computing the B.O.D. load at Station F is given later under the heading "Reduced B.O.D. Load Conditions—Method of Proportions."

Application of Method

After the prediction equations for D.O. drop and natural downstream B.O.D. load reduction have been developed, the equations can be used to predict oxygen concentrations at the low point of the D.O. sag curve under any reasonable conditions of B.O.D. load, temperature and stream discharge.

Normal Load Conditions

If the B.O.D. load at the source is maintained at a normal (mean of the samples) level, the effect on D.O. concentrations at various temperatures and discharges can be determined directly from the two regression equations developed previously. Since there seems to be no correlation of stream temperature with pollution discharge (seasonal influences apparently predominate) desired values of these two variables, within reason, may be inserted in both formulas without danger of setting up an impossible condition. In the D.O. drop formula, the value of B.O.D. concentration at Station F is obtained from the B.O.D. load formula after inserting the selected values of temperature, discharge, and the combined B.O.D. load at Stations A and C.

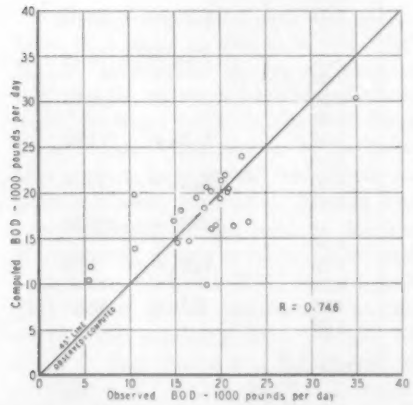

FIGURE 4.—B.O.D. load at station F—observed *vs.* computed values.

For example, assume it is desired to compute the D.O. drop to the D.O. sag for normal load conditions for a temperature of 25° C. and for a flow at Station F of 280 c.f.s. (once in 10-year minimum daily flow). The normal combined B.O.D. load at Stations A and C is 36,360 lb. per day, since this is the mean load of the sampling days listed in Table III.

Solving the load equation for these conditions:

$$\text{B.O.D. load at F} = 12.086 + 0.179 \times 36.36 - 0.394 \times 25.0 + 1.197 \times 2.80 \quad (7a)$$
$$= 12.10 = 12{,}100 \text{ lb. per day}$$

From the general formula, pounds per day = p.p.m. × 5.4 × c.f.s., it is computed that the 5-day B.O.D. value at F corresponding to 12,100 lb. per day there is 8.0 p.p.m. Inserting this value in the D.O. drop formula:

$$\text{D.O. drop} = -1.665 + 0.480 \times 8.00 + 0.208 \times 25 + 0.044\left(\frac{10{,}000}{280}\right)$$
$$= 8.95 \text{ p.p.m.} \quad (8a)$$

From this result it is evident that complete exhaustion of dissolved oxygen at the D.O. sag would occur for these temperature and flow conditions at any time the D.O. concentrations above the point of pollution (i.e., at Station A)

are equal to or less than 8.95 p.p.m. Since D.O. concentrations at Station A as low as slightly less than 7 p.p.m. have been observed, it is obvious that D.O. exhaustion could be expected under certain conditions. Figure 5 has been computed by the same procedure to show computed D.O. drop values under normal B.O.D. load conditions, for temperatures ranging from 15° C. to 25° C. and for discharges ranging from 280 to 1050 c.f.s. at Station F.

Figure 5 shows that the D.O. drop to the D.O. sag curve, at minimum flows and for all summer temperatures, will be sufficient to exhaust the D.O. to zero if only 7 p.p.m. exists above the point of pollution. A D.O. drop to the D.O. sag of about 4 p.p.m. will be produced at a flow as high as 1,000 c.f.s. and at a water temperature as low as 15° C.

Normal Increase in Flow.

The normal increase in flow from station to station, at various levels of flow, was determined from a plot of the river flows on the sampling days at each sampling station against the sampled flow at a selected base station (Station E). If such data are not available, flow increases in proportion to drainage area (assuming no regulation by dams) are reasonably accurate.

Reduced B.O.D. Load Conditions

When stream conditions are to be considered under continuously reduced B.O.D. load (at the source), the reduced effects on D.O. drop of reduced bottom deposits must be evaluated. In this discussion, the simple assumption is made that bottom-deposit effects will be reduced in proportion to the reduction at the source in the B.O.D. load. Obviously there would be a lag in time before the bottom deposits could reflect the reduced B.O.D. load, but after a period of a year or so bottom deposits and their effects on D.O. would become adjusted to the new pollution load conditions.

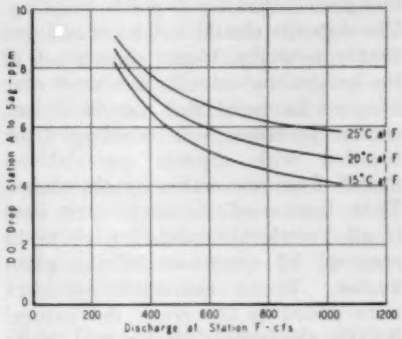

FIGURE 5.—Computed D.O. drop to D.O. sag—normal industrial plant load.

Fortunately, some observed data on bottom deposit effects are available since Industrial Plant is shut down for a few days around Independence Day. For the years 1944 and 1945 shutdown was on July 3 and a set of observations was made on the river on July 5 of both years just prior to the resumption of plant operations. During the shut-down period, the river below the plant has a chance to flush itself of practically all suspended and dissolved B.O.D.

The low B.O.D. values reported on July 5 show only nominal suspended and dissolved pollution, particularly at Stations E, F, and G. At the lower end of the D.O. sag reach, flushing action was not so complete and so the downstream end of the D.O. sag curves observed on July 5 were affected to some extent by suspended and dissolved pollution originating before shut-down. The drop in D.O. observed during these shut-down periods is due primarily to material on the bottom of the river, and secondarily to upstream residual pollution and pollution not flushed out of eddies.

Obviously bottom deposits and slime growths are not stable or constant in amount. A scouring flood would remove them. However, the low-flow period of the summer is usually preceded by a period during which the flows trend downward. It is during

this period that the deposits build up. The deposits should not be considered simply as sludge banks, since much of the bottom undoubtedly is coated with adapted bacterial and fungal slimes, similar to those on a trickling filter, together with organic material removed from the water by the slimes. Thus, bottom effects would exist even if all "settleable solids" were to be removed by treatment of the plant wastes. If no man-made pollution were added to the river, the natural B.O.D. throughout the reach would be about 1 p.p.m. Under these conditions there would obviously be no D.O. sag.

Multiple Correlation Method

Since pollution *is* added to the river, the accumulated material on the bed of the river obviously has an effect on D.O. drop. By inserting 1 p.p.m. B.O.D. in the D.O. drop formula, along with a minimum flow (once in 10-year minimum daily) of 280 c.f.s. at Station F, and a temperature of 25° C. (maximum observed during sampling at Station F was 23.3° C.) the computed D.O. drop due to bottom deposits under these conditions is:

$$\text{D.O. drop} = -1.665 + 0.480 \times 1.0 + 0.208 \times 25 + 0.044\left(\frac{10{,}000}{280}\right) = 5.59 \text{ p.p.m.} \quad (16b)$$

On July 5, 1944, and July 5, 1945, when Industrial Plant was shut down, observed D.O. drop values on these two days, a year apart, were 2.4 and 3.5 p.p.m. (Table I). The D.O. drop values computed to be due to bottom deposits under the conditions prevailing on these two days were 3.5 and 4.2 p.p.m., respectively. Keeping in mind the variation to be expected in any individual observation, it is reasonable to conclude, therefore, that the formula can be relied on to yield reasonably close estimates of the effects of bottom deposits on D.O. drop.

If an immediate chemical oxygen demand is caused by the wastes discharged to the stream, this demand will be attributed in the previous calculations to demand of bottom deposits. Where appreciable immediate oxygen demand is known to exist, correction for it should be made.

The mean total B.O.D. load from previous pollution as determined by the samples at Station A is 2,970 lb. With a mean flow on the days of sampling of 300 c.f.s., the "natural" load at 1 p.p.m. (from natural organic material in any stream) is computed to be 1,620 lb., thus leaving 1,350 lb. of "added" upstream pollution present at Station A, above the point where the waste load from Industrial Plant enters Main River. The "natural" pollution load in pounds per day from above Station A will increase as the stream flow increases, since it is assumed that the natural B.O.D. will remain at 1 p.p.m. for all flows. Similarly, for Plant River the natural load (at 1 p.p.m. in the mean flow) during the sampling days is computed to be 380 lb. per day which, subtracted from the total mean B.O.D. load of 33,380 lb., at Station C, yields 33,000 lb. of "added" load from Industrial Plant discharge.

If the "added" pollution load from Industrial Plant was reduced to 50 per cent of the measured mean, it would then be 16,500 lb. For a minimum flow of 280 c.f.s. at Station F, the corresponding minimum flow at Station A would be 150 c.f.s. Under these conditions, the total B.O.D. load at Stations A and C would be as indicated in the 50 per cent B.O.D. Load Reduction tabulation.

50 Per Cent B.O.D. Load Reduction, Minimum Flow and Maximum Temperature

Station	Discharge (c.f.s.)	B.O.D. Load (lb. per day)		
		Natural	Added	Total
A	150	810	1,350	2,160
C	30	160	16,500	16,660
Total A and C	180	970	17,850	18,820

Now, by inserting the reduced total B.O.D. load at Stations A and C in the load reduction equation, the B.O.D. load at Station F is computed to be:

$$\text{B.O.D. load at F} = 12.086 + 0.179 \times 18.82 - 0.394 \times 25.0 + 1.197 \times 2.80 \quad (7d)$$
$$= 8.96 = 8{,}960 \text{ lb. per day}$$

This B.O.D. load at Station F is equivalent to 5.93 p.p.m. B.O.D. at Station F in a flow of 280 c.f.s.

Using this B.O.D. concentration in the D.O. drop formula:

$$\text{D.O. drop to D.O. sag} = -1.665 + 0.480 \times 5.93 + 0.208 \times 25 + 0.044\left(\frac{10{,}000}{280}\right)$$
$$= 7.95 \text{ p.p.m.} \quad (8c)$$

However, this D.O. drop does not take into account the reduced bottom deposit effect. The D.O. drop due to bottom deposits only, under normal load, minimum flow, and maximum temperature conditions, as computed earlier, is 5.59 p.p.m. The D.O. drop due to reduced bottom deposits after a B.O.D. load reduction of 50 per cent (at the Industrial Plant) will be:

$$\frac{17{,}850}{34{,}350} \times 5.59 = 2.90 \text{ p.p.m.}$$

The value 17,850 is the sum of the normal "added" B.O.D. load at Station A and 50 per cent of the normal "added" B.O.D. load at Station C. The value 34,350 is the sum of the normal "added" B.O.D. loads at Stations A and C. Therefore, the correction to be applied to the computed D.O. drop is $5.59 - 2.90 = 2.69$ p.p.m. The computed D.O. drop of 7.95 p.p.m. reduced by 2.69 p.p.m. yields 5.26 p.p.m. as the corrected D.O. drop to the D.O. sag after a B.O.D. load reduction of 50 per cent at the Industrial Plant. This would result in a D.O. concentration at the low point of the D.O. sag of 1.74 p.p.m., assuming 7 p.p.m. D.O. at Station A.

Figure 6 has been prepared, following the above procedure, to show the D.O. drop to the bottom of the D.O. sag curve under various temperature and discharge conditions and for 50 per cent reduction in plant pollution load.

As a further illustration, a B.O.D. load reduction of 75 per cent at Industrial Plant would produce the conditions indicated in the 75 per cent Load Reduction tabulation.

75 Per Cent Load Reduction, Minimum Flow and Maximum Temperature

Station	Discharge (c.f.s.)	B.O.D. Load (lb. per day)		
		Natural	Added	Total
A	150	810	1,350	2,160
C	30	160	8,250	8,410
Total A and C	180	970	9,600	10,570

$$\text{B.O.D. load at F} = 12.086 + 0.179 \times 10.57 - 0.394 \times 25 + 1.197 \times 2.80 \quad (7e)$$
$$= 7.48 = 7{,}480 \text{ lb. per day}$$

This load is equivalent to 4.95 p.p.m. at Station F, in a flow of 280 c.f.s. at that location.

$$\text{D.O. drop to D.O. sag} = -1.665 + 0.480 \times 4.95 + 0.208 \times 25 + 0.044\left(\frac{10{,}000}{280}\right) = 7.48 \text{ p.p.m.}$$

Bottom deposit effects for the new condition are:

$$\frac{9{,}600}{34{,}350} \times 5.59 = 1.56 \text{ p.p.m.}$$

The correction to be applied to the computed D.O. drop is therefore: $5.59 - 1.56 = 4.03$ p.p.m. Subtracting 4.03 p.p.m. from 7.48 p.p.m. yields 3.45 p.p.m. as the corrected D.O. drop. With 7 p.p.m. D.O. at Station A, the D.O. concentration at the bottom of the D.O. sag curve would then be 3.55 p.p.m.

Following the procedure outlined in the above examples, it is possible to

TABLE IV.—Natural and Added Pollution Loads

Station	Average Flow on Sampling Days (c.f.s.)	B.O.D. Load (lb. per day)		
		Natural (1 p.p.m.)	Measured Mean	Added
A	300	1,620	2,970	1,350
C	71	380	33,380	33,000
Total A and C				34,350
E	487	2,630	24,830	22,200
F	526	2,840	17,820	14,980
G	565	3,050	17,580	14,530
H	756	4,080	16,130	12,050
J	831	4,490	14,680	10,190

compute D.O. concentrations for any reasonable values of B.O.D. load, temperature and stream flow in any desired combination. Stream conditions under reduced pollution loads can be thus predicted, and the extent of needed waste treatment facilities can be evaluated.

Method of Proportions

In those situations where an approximation of the necessary B.O.D. load reduction at the source is sufficient, the B.O.D. load reduction equation is not required. Instead of using this equation, the B.O.D. load at F is approximated by proportion. The mean added B.O.D. load at each sampling station is shown in Table IV and Figure 7.

The B.O.D. at Station F can be approximated for any desired pollution load condition by assuming that B.O.D. loads will be reduced by natural processes, in the river reach between the pollution source and Station F, under various conditions of introduced load, temperature, and flow, in the same proportion as shown in Figure 7 for the mean B.O.D. loads. The B.O.D. at Station F can then be used in terms of p.p.m. in the D.O. drop formula to estimate the drop to the D.O. sag, correction made for bottom deposits, etc.

An example of this procedure applied to conditions of 50 per cent B.O.D. load reduction by waste treatment at Industrial Plant is given in the proportional 50 per cent Load Reduction tabulations.

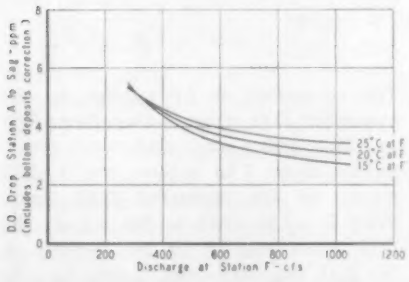

FIGURE 6.—Computed D.O. drop to D.O. sag—50 per cent reduction in industrial load.

Proportional 50 Per Cent Load Reduction, and Minimum Flow

Station	Discharge (c.f.s.)	B.O.D. Load (lb. per day)	
		Natural	Added
A	150	810	1,350
C	30	160	16,500
Total A and C	180	970	17,850

The added B.O.D. load of 17,850 lb. per day at Stations A and C will be reduced by natural processes (it is assumed in this procedure) by the time Station F is reached, in the same proportion that the mean added B.O.D. load at Stations A and C is reduced by time Station F is reached. The 34,350 lb. B.O.D. load at Stations A and C is reduced in this distance by natural processes to 14,980 lb. (Table

IV). By proportion then, the added B.O.D. load of 17,850 lb. will be reduced to 7,780 lb. It is assumed now that this residual added B.O.D. load at Station F will not vary with the discharge and temperature.

The first section of Table V shows the resulting B.O.D. loads in p.p.m. at Station F as the flows vary. By inserting the resulting B.O.D. values at Station F in the D.O. drop formula for a temperature of 25° C., and for various flows, and by applying the usual bottom deposits correction, the second section of Table V results. The last column of this second section of this table shows corresponding D.O. drop values as computed, using the B.O.D. load reduction formula in conjunction with the D.O. drop formula. The third section of the table shows conditions and comparisons for water temperature at 15° C. It appears that the method of proportions for determining the B.O.D. load at Station F produces a fair approximation of the results obtained by the correlation procedure. In some cases this method may be preferred.

TABLE V.—Computed D.O. Drop Values Using Method of Proportions for B.O.D. Load at Station F

For 50 Per Cent Reduction in Industrial Load

Flow at Station F (c.f.s.)	B.O.D. Load at Station F (lb. per day)			B.O.D. at F (p.p.m.)
	Natural	Added	Total	
280	1,510	7,780	9,290	6.14
440	2,380	7,780	10,160	4.28
620	3,350	7,780	11,130	3.32
840	4,530	7,780	12,310	2.71
1,050	5,670	7,780	13,450	2.37

For Temperature of 25°C.

Flow (c.f.s.)	Uncorrected D.O. Drop (p.p.m.)	Bottom Dep. Correction (p.p.m.)	Corrected D.O. Drop (p.p.m.)	
			Prop. Method	Correl. Method
280	8.06	2.69	5.37	5.26
440	6.59	2.41	4.18	4.35
620	5.84	2.27	3.57	3.88
840	5.36	2.18	3.18	3.57
1,050	5.10	2.13	2.97	3.40

For Temperature of 15° C.

Flow (c.f.s.)	Uncorrected D.O. Drop (p.p.m.)	Bottom Dep. Correction (p.p.m.)	Corrected D.O. Drop (p.p.m.)	
			Prop. Method	Correl. Method
280	5.98	1.69	4.29	5.44
440	4.51	1.41	3.10	4.06
620	3.76	1.27	2.49	3.36
840	3.28	1.18	2.10	2.91
1,050	3.02	1.13	1.89	2.66

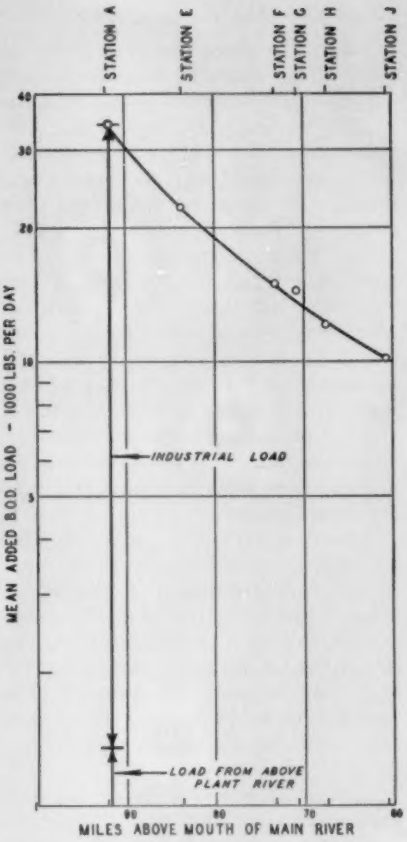

FIGURE 7.—Progressive downstream reduction in B.O.D. load.

Algae and D.O. Concentration

Effects of algae are present in the Main River above Plant River and at the tributary stations. The quantity of D.O. normally added to a relatively clear stream by algae varies considerably throughout the day and night during the warm months of the year. Pollution, both domestic and industrial, clouds the receiving waters to some extent and thus reduces the extent of light penetration. This, of course, reduces photosynthesis and the production of oxygen by algae. Observations of D.O. about dawn are the least influenced by algae, and, of course, usually show the lowest actual concentration. This fact is well known and is often used in evaluating critical conditions.

Direct observations have indicated the almost complete absence of algae in the heavily polluted section of the river. Furthermore, frequent observations during a 24-hr. period at one station failed to show any change in D.O. concentrations in passing from daylight to darkness, and vice versa, that could be attributed to algal activity.

In those streams which are affected both above pollution and throughout the D.O. sag reach, the disturbing effects of algae-added oxygen can be minimized in computations. This is accomplished by observing D.O. concentrations through the reach as simultaneously as possible so all observations will be in the same part of the oxygen-added (or oxygen used at night) algal cycle.

Desirable Field Observations

Sampling Stations

To secure the most desirable field information at the most reasonable cost, four sampling stations should be established. Station 1 should be just upstream from the point where the pollution under study enters the stream.

Station 2 should be located as close below the pollution source as possible and yet get accurate data. It must be kept in mind that even with multiple-point sampling across a stream it is difficult to obtain accurate results when the stream is wide. However, if sampling is not performed reasonably close to the pollution source considerable reduction in the pollutional load from the outfall sewers farthest upstream will take place in the reach between this location and Station 2. It will undoubtedly occur to some to measure the total B.O.D. load by sampling and measuring the flow in all outfall sewers. The load so measured, however, may be a far cry from the B.O.D. load measured at Station 2. This is true because of the vast differences existing in the B.O.D. bottles under these two conditions. Waste concentrations, toxic materials, seeding organisms, nutrients and possibly other factors vary considerably. Comparable results should not even be expected.

Station 3 should be located as near the low point of the D.O. sag at low flow as possible. If no bridge is available reasonably near this location, a boat should be used. Station 4 should be located approximately half-way up on the recovery end of the D.O. sag as it exists for low-flow conditions.

At each of these four stations D.O. and temperature observations should be made and B.O.D. samples collected. Since stream flows are basic to any pollution study at least one stream gaging station should be located in or near the reach under study. Accurate estimates of flows at each station should be made from the records at the stream gage by drainage area proportions, runoff per square mile as indicated by a small local gaged tributary, or by other means.

The four D.O. values, one at each station, should be sufficient to enable the investigator to draw an accurate D.O. profile for each set of samples

collected. Since the D.O. drop from Station 1 to the low point on the D.O. sag curve is an important item in the study, the profiles must be very carefully drawn. Water temperatures at each station are very useful. If there is substantial heating of the stream by some industrial operation that utilizes a significant portion of the total stream flow, it will be desirable to use reach temperatures of this section of the stream in the computations.

At Station 1 B.O.D. samples are needed to measure the B.O.D. load coming from upstream so this load can be separated from the B.O.D. load under study. The need for B.O.D. data at Stations 2 and 3 is obvious. At Station 4 B.O.D. samples are not essential but will be useful in case the proportionate method of determining the progressive downstream decrease in B.O.D. load is preferable in the analysis to the multiple correlation procedure. Furthermore, where it is especially difficult to obtain an accurate measure of the pollution load near the source (wide river, pollution on one side only, etc.), it may be desirable to estimate the load at the source by projecting upstream the pollution loads measured at the downstream stations from a plot like that of Figure 7.

In some situations, pollution discharged to a stream may be mixed in a relatively short river distance with the flow of the stream. In this case the B.O.D. load would need to be measured at one station only, and that station could be quite close to the pollution source. The D.O. drop to the D.O. sag curve could be correlated with B.O.D. concentrations at this point directly in the D.O. drop formula. Having such a correlation the needed reduction in load at the source could be easily calculated using the D.O. drop formula only.

Frequency and Number of Samples

Sampling at weekly intervals during a summer and fall season will result in some 18 or 20 sets of samples and D.O. profiles. These should produce enough data to yield reliable prediction equations. If the data collected correlate well, as judged by the value of the coefficient of multiple correlation, even fewer sets of data may be sufficient. If the data do not correlate well, then more samples will be necessary. In other words, the consistency of the data collected, and the desired accuracy, will determine the number of sampling runs necessary. It should be recognized that the accumulation or scouring of bottom deposits will affect the consistency of the data.

All stream samples should preferably not be collected on the same day of each week, or the same hour of each day. At least a few sets of observations at night would be desirable. Critical D.O. conditions usually occur just before dawn.

Since the method of analysis proposed herein correlates a number of variables, it is desirable (in fact, essential) to observe during the sampling period a considerable range in each variable. This does not imply, however, that data for flood discharges are desirable. Since the usual application is to determine the degree of needed treatment for critical flow and temperature conditions, the most useful data will be those which are in the range between average and critical conditions. This means less extrapolation will be necessary and yet sufficient variation will be available to establish reliable partial regression coefficients for each independent variable. Having these, a reasonable extrapolation can be made with confidence.

It should be realized that the least squares procedure for determining the partial regression coefficients makes the sums of squares of observed deviations from the computed regression a minimum. While this is very desirable, it at the same time gives weight to a single observation that is far outside the range of all the others in one

or more respects (D.O. drop, B.O.D., temperature, or discharge). If only a few such extreme values are available, the weight of a large number of values nearer the means may prevent the extreme values from falling close to the computed regression. This may result in extreme conditions not being predicted accurately. Improvement would result if the observations were more evenly distributed over the range of all variables.

Statistical Considerations

The question will arise in the minds of those concerned with statistical theory as to why the authors, in setting up the basic form of the D.O. drop prediction equation, enter B.O.D., temperature, and discharge in the equation as shown. There is evidence to show that each of these "independent" variables varies linearly (or nearly so) with the dependent variable D.O. drop. Therefore, a linear type regression was selected for correlating all the variables.

Linear Variation of Variables

Linear variation of the B.O.D. with the D.O. drop is quite obvious, since it is the B.O.D. exerted in a bottle sample that produces a decrease in D.O. in the bottle sample. The dilution technique of B.O.D. determination is based on the assumption that the relationship is linear. Temperature effects on D.O. drop are not so obviously linear but extensive experimental work by Gotaas (4) indicated a linear relationship of 5-day B.O.D. to temperature. The rate of reaeration increases with temperature but not strictly linearly. Since the effects of temperature on both deoxygenation and reaeration are included in the temperature factor, the authors do not feel justified at this time in attempting any refinement beyond using the temperature to the first power. Experience has demonstrated that if D.O. drop is plotted against the reciprocal of discharge, a linear relationship results. The work of Le-Bosquet and Tsivoglou (5) supports this conclusion, although they used the D.O. directly instead of D.O. drop.

Consideration of the B.O.D. load reduction regression leads to a plot of the B.O.D. load at Station F against the combined B.O.D. loads at Stations A and C. This plot indicates a poor simple correlation because of the abruptly changing B.O.D. load at Station C, and because the influences of temperature and discharge are not included in the simple correlation. Similarly the nature of the effects of temperature and discharge on the B.O.D. load at Station F are not revealed in simple two-variable plots. However, when the multiple correlation approach is carried out, a reasonably high coefficient of multiple correlation is obtained as shown by Figure 4. The authors now conclude, therefore, that nothing more complicated than a linear correlation is justified for the B.O.D. load reduction regression. Further study may alter this tentative conclusion.

Coefficient of Multiple Correlation

It is difficult to find in statistical references a good, clear definition of "coefficient of multiple correlation." However, Ezekiel (6) has this to say: "In simple correlation, the relative importance of the independent factor was measured by the ratio of the standard deviation of the estimated values to the standard deviation of the actual values, and the name coefficient of correlation was given to this ratio. In exactly similar manner, when the estimates are based on several variables, instead of on one, the relative importance of all those variables combined may be measured by dividing the standard deviation of the estimated values by that of the original values. This ratio is named the coefficient of multiple correlation, since it measures the combined importance of the several independent factors as a means of ex-

plaining the differences in the dependent factor."

When values of the coefficient are near 1.00 the values computed by the formula are quite close to the observed ones, thus showing the formula explains almost all the variation in the original observations. When values of the coefficient are not so close to 1.00, but tend toward zero, then the formula does not explain the observed variation very well.

The coefficient of multiple correlation, R, can be computed (6) from the equation:

$$R^2 = \frac{b_1(\Sigma yx_1) + b_2(\Sigma yx_2) + b_3(\Sigma yx_3)}{\Sigma(y^2)} \quad (9a)$$

For the D.O. drop formula this coefficient is:

$$R^2 = \frac{(.480)(47.14) + (.208)(137.49) + (.044)(123.74)}{75.06} = 0.7550 \quad (9b)$$

$$R = 0.869$$

For the number of observations, and the number of variables, statistical significance at the one per cent level is reached at a value of 0.652. Obviously, the value of 0.869 is statistically highly significant.

For the B.O.D. reduction formula the value of R is 0.746. This somewhat lower value is probably the result of the intermittent nature of the B.O.D. load put into the stream at Industrial Plant. However, statistical significance at the 5 per cent level is reached at a value of 0.563, and at one per cent level at a value of 0.652. Thus the correlation is found to be highly significant in spite of the sudden load fluctuations.

Confidence Limits

Since the prediction equations are developed statistically, it is possible to compute confidence limits for the regressions. One of the most useful methods is that of Snedecor (7). The 95 per cent confidence limits for the D.O. drop formula, when all variables are at their means, shows that the computed value of the regression is within ± 0.41 p.p.m. of D.O. drop of the true value. By true value is meant the regression established by an infinite number of samples. When the independent variables are at their observed extremes (maximum B.O.D. and temperature and minimum discharge), the regression is within ± 1.14 p.p.m. of the true value, with a probability of 19 to 1 (95 per cent C.L.). The chances are 19 to 1 that a single observation will be within ± 2.04 p.p.m. of the value computed by the D.O. drop formula when the variables are at their means, and within ± 2.31 p.p.m. when the variables are at their extremes.

For the B.O.D. load reduction formula, when all variables are at their means, the computed B.O.D. load at Station F, with a probability of 19 to 1, is within ± 1,800 lb. per day of its true value. This amount of variation is almost exactly 10 per cent of the mean B.O.D. load at Station F. For the maximum B.O.D. load at Station A plus C, the maximum temperature, and the minimum discharge, the 95 per cent confidence limits of the computed load at Station F vary 5,600 lb. per day on either side. This demonstrates the increasing uncertainty of the accuracy of computed values for conditions at and beyond the extremes of the observed range.

By means of the confidence limit calculations, the investigator may decide for himself if the results he is obtaining are sufficiently dependable for his needs. If the results do not satisfy him, he will know he needs more data, and probably a better distribution of data.

D.O. Drop to a Specific Location

If for some special reason the D.O. drop (and consequently the D.O. concentration) to some specific fixed location on the D.O. sag curve is desired,

the method can be easily adapted to this situation. In place of using the observed D.O. drop to the bottom of the D.O. sag in the D.O. drop formula the D.O. drop to the location under study can be used. The B.O.D. load reduction regression is similarly modified. The calculations are carried out as illustrated for the drop to the D.O. sag.

Downstream from an Impoundment

The authors have studied a situation below a series of deep impoundments where the water discharged from the low level outlets in the dam at the downstream end of the series contains low concentrations of D.O. during the warmer months of the year when thermal stratification of the reservoirs exists. A short distance (4 miles) downstream from the dam an industrial city discharges its domestic and industrial waterborne waste into the river. The stream has an oxygen deficit along the shore where the waste is discharged but, until the waste is added, it also has a very low B.O.D. since the oxygen demand of upstream pollution has been almost completely satisfied during long storage in the upstream pools. The rate of reaeration of this water is high since the surface rate of reaeration is directly proportional to the saturation deficit.

During low flows in the controlled river, the pollution added by the city results in complete D.O. exhaustion a few miles farther downstream. During high controlled flows (above half-capacity of the power units in the dam) the added pollution merely slows up the rate of reaeration, and D.O. concentrations in the river continue to increase from the dam to a point many miles downstream where near saturation is reached.

In analyzing this situation to determine the quantitative effects of all the pertinent variables on the D.O. concentration, the oxygen deficit just above the city is an important consideration. It was found that in working out a multiple correlation of the D.O. drop with the usual variables, the addition of another variable to take the initial oxygen deficit into account improved the correlation materially. After several attempts to work out the theoretical form of this factor in the equation, the empirical relation $\frac{\text{Deficit}}{\sqrt{\text{Discharge}}}$ was found to yield the best multiple correlation coefficient. The final equation worked out was:

$$\text{D.O. drop} = -0.680 + 0.028(\text{B.O.D.}) + 0.138(\text{temp.}) + 0.323\left(\frac{10{,}000}{\text{c.f.s.}}\right) - 0.304\left(\frac{\text{Deficit} \times 100}{\sqrt{\text{c.f.s.}}}\right) \quad (10)$$

For this situation B.O.D. values ranged from 4.2 to 58.7 p.p.m., temperatures from 12.7 to 25.6° C., discharges from 370 to 4,200 c.f.s., and oxygen deficits above pollution from − 0.4 to 7.48 p.p.m.

For the higher observed flows the D.O. drop was negative, as explained previously, and the prediction equation, of course, yielded negative values for this condition. The coefficient of multiple correlation was 0.952. This value is highly significant since the value of R for the one per cent point is 0.516 for the number of observations and variables considered.

Conclusions and General Comments

The authors believe the proposed method of stream analysis is worth considering by a pollution control agency, municipality, or industry that has a desire to determine the pollution absorptive capacity of the receiving stream. Only after such studies are made can realistic degrees of needed waste treatment be determined.

Application of the method requires brief, periodic, observations of stream conditions over a period of several months. During this period a range

of conditions will be observed, and the prediction equations resulting are more reliable for critical conditions.

Since water travel data are not needed, and since long-term incubation of B.O.D. samples is not necessary, the cost of collecting the necessary data is reasonable. This is particularly true for industries and municipalities studying only one local river reach, but it is also true for agencies studying a number of river reaches in the same general area inasmuch as several reaches can be sampled on the same field trip.

The authors are well aware that this approach to stream analysis is a radical departure from previous methods. They also recognize that the procedure discussed herein can be improved materially as more experience with it is obtained.

Acknowledgments

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REMEMBER LOS ANGELES, OCTOBER 8–11, 1956

How are you going to the Los Angeles Meeting? There are many ways, but your trip will be a memorable one if you join others by special train from New York via Chicago. A postcard or letter to the Federation office will help with such arrangements.

Don't miss the year's top gathering of people and equipment in the sewage and industrial wastes field.

REMEMBER LOS ANGELES, OCTOBER 8–11, 1956.

Research Forum*

The idea of a Research Forum as an integral part of the Annual Federation Meeting has been in the minds of various persons for a number of years. The increased emphasis on research needs in sewage and industrial wastes made the inclusion of this subject in the Annual Meeting Program most appropriate. The Forum provides research personnel and others interested in research an opportunity to meet and discuss projects and mutual problems.

Response to the first Research Forum held at the 1955 Annual Meeting of the Federation was most gratifying. University faculty members engaged in research work were enthusiastic in providing a selection of papers for consideration. Meeting attendance and participation in discussion were excellent. Accordingly, the Board of Control has approved in principle the Research Forum as a regular feature of the Federation's Annual Meeting.

The leader of the 1955 Forum was George E. Symons, consultant and technical editor, of Larchmont, N. Y. At the session, each participant presented a 25-minute oral commentary on his research work. The papers presented in this section of the Journal are the formal manuscripts prepared by the Forum participants.

BIOLOGICAL PURIFICATION OF CITRUS WASTES

By James B. Lackey, Wilson T. Calaway, and George B. Morgan

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Almost any organic compound is susceptible to attack by some living organism. Those organic mixtures which are attacked by the greatest variety of organisms are usually readily soluble, are approximately neutral, are nontoxic to living protoplasm, are short-the volume of fruit treated are certain available phosphorus in excess of 0.01 p.p.m. and nitrogen in excess of 0.2 p.p.m. As a substance is removed more and more distant from these conditions, fewer and fewer kinds of organisms use it as a source of energy, until at the greatest extremes of environment, the compound is virtually unassailable.

There are some 40 citrus processing firms in Florida and their number and the volume of fruit treated are certain to increase. They all produce some wastes and in many cases, treatment by dilution is impossible, or will be eventually. Therefore, it has become highly pertinent to consider the treatment of this type of waste.

Citrus wastes are quite variable in composition from one processing plant to another and with time. Depending on what operations a processor carries out, the wastes may range from a thin watery material with a low B.O.D. value to press liquor, which is an "extreme" waste high in B.O.D. The larger processors, however, will have mixtures approximating the "normal"

TABLE I.—Analysis of Citrus Wastes

Determination	Press Liquor	Citrus Wastes (normal)
pH range	3.8–6.4	3.92–4.68
Brix scales[1] (°)	10.1	1.12
Total solids (%)	5.63	0.609
Total sugar (%)	6.63	1.20
Pectin (%)	0.34	0.014
Protein (N ×6.25) [%]	0.31	0.075
Essential oils (per cent by vol.)	0.23	0.41
B.O.D. range (p.p.m.)	35,000–55,000	3,500–8,800

[1] Arbitrary hydrometer scale for expressing specific gravity of liquids, especially sugar solutions.

* Presented at the 28th Annual Meeting, Federation of Sewage and Industrial Wastes Assns.; Atlantic City, N. J.; Oct. 10–13, 1955.

waste shown in Table I. The available phosphorus is not shown; some is present but not sufficient to give a satisfactory nitrogen to phosphorus ratio (N/P), or enough total quantities of either. Based on some previous studies, however, it would seem that such substances are amenable to biologic attack.

Actually these wastes can be purified by anaerobic biologic action but the process is lengthy. Furthermore, the action produces exceedingly objectionable odors. It is virtually impossible to impound the liquors for a sufficient storage time for complete purification; any storage must be in the open because of the volume concerned, which augments the odor problem. In addition, the pH range is subject to wide and destructive changes because alkali from the wash-up operations is added to the processing plant effluent at varying intervals. These factors interfere with anaerobic treatment.

Any satisfactory solution to the citrus waste problem must satisfy a number of criteria. The treatment process must be geared to the economy of the particular processing plant. It must be operative for only a portion of the year. Excessive odor production must be avoided because frequently the citrus plants are in heavily populated areas. Furthermore, the process must be flexible enough to operate at varying loads. Fluctuations in the pH value of the waste must be smoothed out. Finally, there must be made available additional nitrogen and phosphorus. These conditions indicate the complexity of the problem.

Treatment

Review

The only methods of treatment in vogue when this study was initiated were dilution and lagooning. At Plymouth and Winter Haven, Fla., wastes were settled as much as feasible, and allowed to pass through a long series of shallow lagoons. These provided variable detention times, but generally speaking, the reduction in B.O.D. was not satisfactory or else there was none. Dissolved oxygen was not acquired and odors were a serious problem.

The Florida State Board of Health operated a citrus waste research project (1) at Plymouth from March, 1952, to June, 1953. The results of this study were stated to be encouraging, and the data amply proved the point. Raw citrus wastes from a processing plant were used in the studies. More recently Dougherty, Wolford and McNary (2) reported on the results obtained with the activated sludge method of treatment using a reconstituted waste made from orange juice, diluted with tap water. McNary *et al.* (3) (4) (5) had previously reported on attempts at anaerobic treatment. McKinney, Poliakoff and Weichlein (6) considered the problem of nitrogen deficiency in relation to treatment.

Experimental

Since no satisfactory treatment was in use, the initial work was to determine the biota concerned with the breakdown of citrus waste. On microscopic examination bacteria, yeasts, green flagellates, principally of the genera *Euglena, Chlorogonium* and *Chlamydomonas,* were identified; in addition, a few ciliates and colorless flagellates of anaerobic types were found. The last lagoons in the series of lagoons at Plymouth and the lake beyond, although green at times with the above mentioned flagellates, showed no dissolved oxygen. The trickling filters in the work by O'Neal at Plymouth had a more extensive biota (1), enough to indicate the possibility of a balanced population under conditions of aeration.

A primary consideration for any of the following methods of treatment has been to obtain as much settling as possible, followed by lime addition to

bring the pH value up to approximately 9.0.

Contact aeration was first tried using a mixture of citrus waste and domestic sewage which was allowed to flow over baffle plates. Good balanced biotas were developed, but only as long as the citrus waste was not allowed to exceed 20 per cent of the mixture. In 4 hr. a B.O.D. reduction of 39 per cent was achieved, and the effluent was clear. This indicated possible treatment in municipal sewage treatment plants, as long as the dilution factor was 5 to 1 or greater. Since nitrogen and phosphorus were present in the sewage, it also indicated the advisability of adding them if higher concentrations of citrus waste were treated.

Contact aeration in a small lagoon system (Figure 1) was tried next. Here again it proved necessary to keep the dilution with raw sewage as high as 80 per cent. In addition, heavy scums formed on top and interfered with atmospheric aeration. An extensive overhead sprinkling system using lake water was constructed over the lagoons at Winter Haven. This prevented scum formation, but since no sewage (nitrates, phosphates) was added the process continued to be anaerobic and odor production was increased.

FIGURE 1.—Concrete lagoon system for citrus waste studies, University of Florida, Gainesville, Fla.

Two 48-gal. activated sludge tanks were constructed next at the Sanitary Research Laboratory of the University of Florida. One run of these units has resulted in as high as 67 per cent B.O.D. reduction when the initial loading was 3,500 p.p.m. of B.O.D. At this time an addition of 50 p.p.m. of nitrogen (as NH_4NO_3) was being made. The biota consisted almost entirely of branching fungi (*Phycomycetes*). However, a badly bulking sludge was formed and the B.O.D. removed from solution was, of course, incorporated in this sludge. Unless such sludge can be settled out, and removed with its load of B.O.D., the process becomes virtually useless.

A trickling filter was constructed at Winter Haven and loaded with well-aerated (6 hr.) citrus waste to which the equivalent of 50 p.p.m. of nitrogen had been added. An excellent biota developed. After a series of biotic successions, a stable flora and fauna resulted, and this two-stage process gave the most promising results to date. Long aeration time can be secured at not too great cost, but the filter size necessary for large volumes of processing plant effluent would be very costly. This process, while successful, does not now appear too promising because of cost. At present it is uncertain as to whether the effluent from this filter can be aerobically lagooned.

Lagooning at Winter Haven, following 4 to 7 hr. of aeration, addition of nitrate, and some dilution with lake water, has been intermittently successful. At times the lagoons have developed a fairly good stagnant water biota. But any upset, such as a heavy slug of caustic coming through, would invariably upset this balance and bring a return of anaerobic conditions.

Citrus processing plants close in the summer and open perhaps as late as

November first. Impracticability of freezing, storing and shipping several hundred drums of normal citrus waste led to the use of press liquor at the Sanitary Research Laboratory, since one volume of press liquor can be diluted up to 12 times to produce a B.O.D. of 2,000 to 3,500 p.p.m.

Laboratory experiments with this waste have demonstrated that if nitrogen and phosphorus are fed and aeration continued for 8 to 10 hr., excellent sludges which settle well and accomplish up to 90 per cent purification can be produced. These sludges have a good mixed biota, including large quantities of *Zooglea ramigera*. This last development in treatment is the most promising thus far. It, too, has problems, one being the occasional occurrence of a viscous condition. Attempts to develop a sludge "adapted" to no-nitrogen feed have not been successful, but the cost of feeding is not prohibitive.

The Biota

Yeasts, Bacteria, Fungi

The waste is invariably seeded with bacteria, yeast and fungus spores from the raw fruit washing, in addition to the process plant wash water. It has been demonstrated that the yeasts almost immediately ferment the sugars, and there is consequently a quick loss of dissolved oxygen and a rapid drop in the pH value so that the action of the yeast is short lived. Aeration prolongs it but only for a limited time. Below a pH value of 4.0 or 4.5 the yeasts cease to function, if one may judge by their low numbers and the absence of budding cells.

Many free-living non-zoogleal bacteria also are present in these early stages and recent papers by Barker (7) and Nickerson (8) indicate that these may be organisms such as *Acetobacter* and *Leuconostoc*, tolerant of acid, facultative, and perhaps active in transforming certain waste components into ketones and alcohols which are then utilized by methane producing bacteria. Certainly methane formation begins after considerable fermentation has occurred. There is also a quick breakdown of at least some of the protein of the press liquor (a part of this is due to enzymes liberated from the crushed fruit). Since there are no microscopic animals present and limited quantities of fungi, it appears that this is the type of process described by Delwiche (9) in which ammonia is formed. Indeed, ammonia may be formed to such an extent as to be easily detected by odor. Furthermore, under aeration there is no production of objectionable odor.

If, following aeration but without feeding nitrogen or phosphorus, the waste is allowed to flow slowly through lagoons, it quickly becomes anaerobic and methane production results. Some of this gas could be produced from readily available carbon dioxide, but organisms resembling *Sarcina methanica* and *Methanobacterium* are abundant in the lagoons and are probably in an optimum milieu. At the same time, the odors are suggestive also of sulfides and amines.

Zooglea ramigera and *Sphaerotilus* are never visible under these conditions. This is rather interesting too, because *Sphaerotilus* grows in vast abundance in the barometric-leg water, which contains only a small amount of organic matter. However, it probably utilizes the sulfur abundant in this water.

Prolonged aeration, however, especially of diluted waste or followed by feeding nitrogen and phosphorus, produces good growths of *Zooglea*, presumably *Z. ramigera*. It also produces heavy growths of fungi and some *Sphaerotilus*. The fungi which are easily isolated and presumably most abundant are shown in Figure 2. Because of the substantial reduction in B.O.D. when the fungi were abundant, studies of their effectiveness in pure culture are under way. The appara-

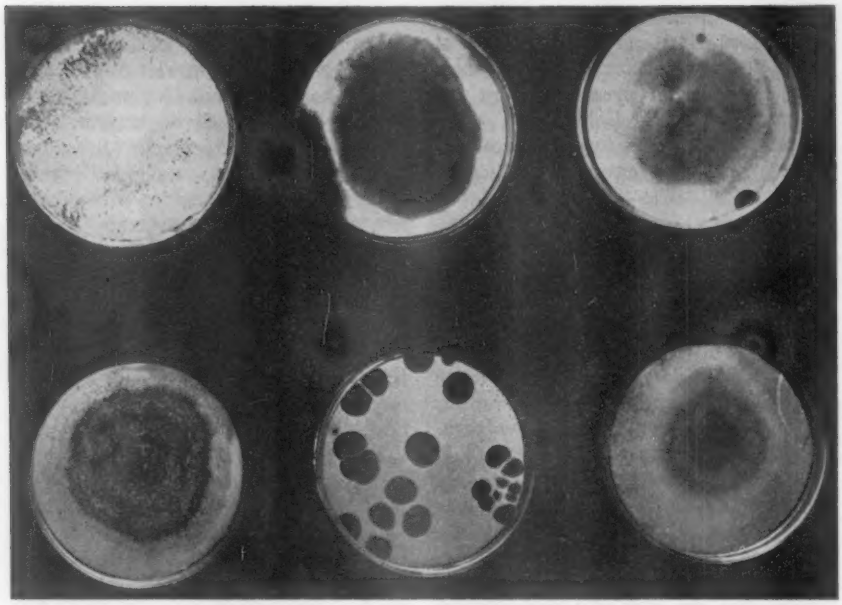

FIGURE 2.—Fungi isolated from citrus waste.

tus for this is shown in Figure 3. Assuming that sterilizing the waste does not change its composition too greatly, the reduction accomplished by any single species of fungus thus far has been lower than that accomplished by a mixed biota. On the whole, the best oxidized sludges have been produced when a mixture of fungi, dominated by *Zooglea,* has been present.

Flagellates

The above floras have been characteristic of high carbon, low nitrogen, low phosphorus substrates. The carbohydrate materials such as sugars and citric acid, etc., also support at times large flagellate populations. Mention has been made of *Euglena gracilis, Chlorogonium euchlorum, Chlamydomonas sp.* and at times *Spondylomorum* as common to the Plymouth lagoons. These same species also occurred at Winter Haven and at times in the experimental waste treatment plants at Gainesville. They typically synthesize starch, as does one of the colorless flagellates, *Polytoma,* also abundant at times.

Most common are anaerobic flagellates, which are bacteria-eaters. Although they never attained the numbers of the green forms, it is doubtful if any green or colorless flagellate ever attained significant numbers in any of the treatment processes.

Ciliates, Other Microscopic Forms

Vorticellids are generally supposed to indicate a good sludge if present in large numbers. These and other free-living aerobic ciliates at times were abundant in the experimental waste treatment plants, including the trickling filter. But the lagoons rarely contained any ciliates; when present they were generally anaerobes. Ciliates never appeared as abundantly or in as great diversity as in activated sludge or trickling filter film from domestic sewage treatment plants. Neither did amoebae or, for that matter, bacteria-eating flagellates.

Altogether, it was inferred that none

of the methods of treatment produced a well balanced substrate, and that such oxidation as could be secured must be the work of a limited group—an "adapted" group. There is nothing wrong with such a situation. But if it exists, it should be recognized and any manipulation of the situation should be directed towards favoring those organisms doing the effective work. This was well demonstrated in the Winter Haven trickling filter, which at first was colonized by fungi and yeasts. Then the yeasts supported a large population of the small fly, *Drosophila*. These were succeeded by other flies, nematodes, and finally a fairly stable population of fungi and protozoa, which was quite effective in B.O.D. reduction.

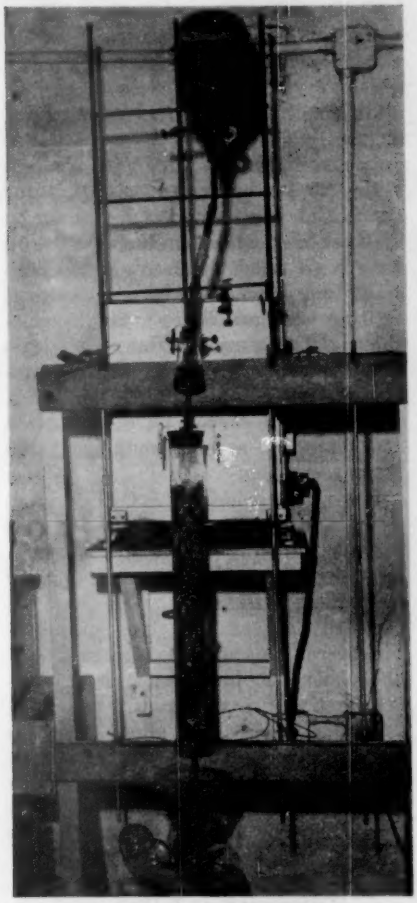

FIGURE 3.—Laboratory apparatus for studying removal of B.O.D. from citrus waste by one species of organism. Upper bottle contains sterile waste which trickles through cylinder inoculated with a single species.

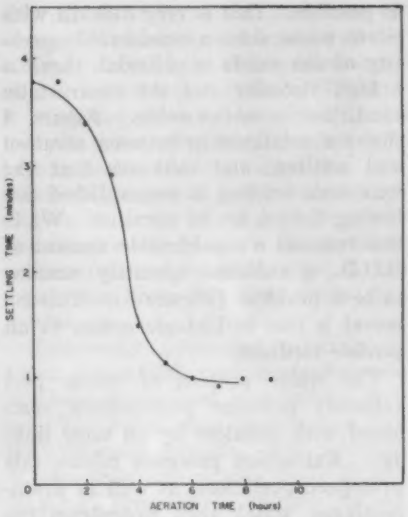

FIGURE 4.—Maximum settling of citrus waste solids occurs between 2 and 4 hr. aeration.

Chemical Aspects

Reference to composition of citrus wastes has already been made. Inherent factors deterrent to biological treatment are:

1. Imbalance due to high carbon, low nitrogen, low phosphorus.
2. Low pH, 3.5 to 4.7, due to as much as 35 g. per liter of citric acid, in addition to citric-acid salts.
3. Toxicity of the soap used for producing added color.
4. Toxicity of one fraction of peel oil.
5. Fluctuations in composition.
6. High B.O.D.

The first step in removal of B.O.D. was to settle out as much of the solids

as possible. This is very difficult with citrus waste, since a considerable quantity of the solids is colloidal, there is a high viscosity and the electrostatic condition is unfavorable. Figure 4 shows a relationship between aeration and settling, and indicates that the maximum settling is accomplished following 2 to 4 hr. of aeration. While this removes a considerable amount of B.O.D., a sufficient quantity remains to be a problem (Figure 5). This removal is due to biologic action in an aerobic medium.

The white portion of citrus peel (albedo) contains protopectins combined with cellulose by an ester linkage. Extraction processes release this protopectin-cellulose, as well as protopectinase, which then hydrolyzes the linkage, converting the insoluble protopectin to soluble pectin. This is a hydrophyllic colloid, slightly negatively charged—a molecule with a large shell of hydration. If the pH value is raised from about 3.5 to 7.0 (a desirable step) with strong alkali, the pectin is converted to pectic acid by demethoxylation. Pectic acid is insoluble, will not settle, and is largely immune to biologic attack.

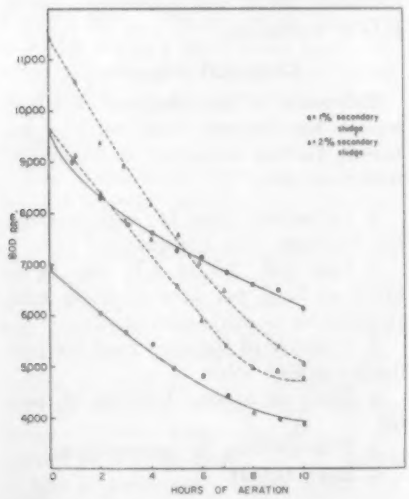

FIGURE 5.—Relation between decrease in B.O.D. and hours of aeration.

Pectin removal may be accomplished in part by fungi developing in aeration tanks where the detention time is 6 hr. or longer. Enzymes produced by the fungi, such as demethoxylases and polygalacturonases, break the long carbon chains, producing polygalacturonic acid which is susceptible to biologic attack. The fungi will thrive at a lower pH value than oxidizing bacteria and protozoa but the addition of lime to raise pH values to about 7.0 enhances all biologic action (of an aerobic type) and aids settling. In addition, it breaks the citric acid-citrate buffer system; once broken, only small amounts of alkali are necessary to further raise the pH. But the initial requirement may be large.

Other methods of inducing settling have been tried. Screening and centrifuging have not been successful (within economic limits), nor has mechanical flocculation. Many chemicals such as ferric chloride, ferrous ammonium sulfate, alum, activated silica and activated carbon have been tried and discarded as not producing satisfactory settling.

Since the principal B.O.D. component is carbohydrate in the form of sucrose, reducing sugars and starches, the pH problem is due largely to their incomplete oxidation. The lack of nitrogen accentuates the problem. Therefore, supplying nitrogen and phosphorus should permit more biologic activity, maintain pH values at desirable levels, and allow complete oxidation. This is also the reason for a long aeration period. As long as the process is kept aerobic, no odor problems from mercaptans, amines or sulfides are present.

Discussion and Resume

Most natural waters receive organic substances in the natural course of events. These may be human and animal excrement, bodies of dead animals,

dead vegetation, or complex wastes from manufacturing processes. The usual succession of organisms in destroying these wastes is a sixfold succession: bacteria; colorless flagellate and amoeboid protozoa; ciliate protozoa, rotifers and minute worms; green algal forms; crustaceans, and insect larvae; and fish. The green algal forms are continuously active after they once appear, until the cycles of mineralization and transformation of dead organic matter into living bodies are completed.

Any deviation from this succession indicates some particular quality of the organic substrate. Blocking of the succession indicates a toxic agent; the appearance of large yeast populations may indicate large quantities of sugar. Nevertheless, the initial statement that virtually any organic substance is open to biologic attack remains true, and destruction of any waste becomes a question of determining the manipulation necessary to make that destruction a satisfactory one.

Cost

Prime consideration is given to cost. If destruction of citrus waste is so costly as to make the price of citrus concentrate prohibitive, the process is useless. Bearing this in mind, the use of the refuse from the processing operations as by-products has been exhaustively explored by the citrus processors. The use of dilution, where sufficient, is herein advocated, but with the caution that it is a dangerous expedient and must be kept under careful observation. Anaerobic treatment in open lagoons is unsuccessful because of slowness and the development of odor. Closed tanks for such treatment are deemed too expensive because of the great volume which must be handled.

Aeration

Aeration alone is a help, either in an aeration chamber or a trickling filter. But because of the large amount of suspended solids, and because of the buffer systems of the liquor, it removes an insufficient amount of B.O.D., and it is accompanied by a quick drop in the pH value, hindering further biologic attack following aeration. Removal of as much suspended matter as possible is therefore necessary. Of the many methods tried, the addition of lime followed by mechanical flocculation has thus far been most successful.

Sufficiently prolonged aeration to allow the initial step in destruction has been determined to require 6 to 8 hr. The initial step in this case is a bacteria-yeast process. The addition of phosphate and nitrate, up to 10 and 50 p.p.m. respectively, enables the second and third steps in succession to occur. If pH control is included, the third step is aided greatly and the fourth step will occur. It would seem that the waste treatment plant effluent is ready at this stage for a discharge to a receiving water.

One further factor has proved troublesome, at least in the laboratory. This is bulking of the sludge in the aeration process. It has not been uncommon to develop a process whose reduction reaches 80 per cent. Unfortunately, the sludge frequently refuses to settle. Examination may show an abundance of *Zooglea ramigera*, ciliates, a few flagellates and rhizopods, and massive growths of *Sphaerotilus*. The B.O.D. has been removed from solution, and is in the bodies of the organisms mentioned. But unless these bodies can be settled out and withdrawn, the B.O.D. loading will be returned upon their decay. It appears that bulking is at present an unsolved problem.

Effluent Discharge

Whether or not the effluent can go into a receiving stream is still dependent on several factors. One of these is the dissolved oxygen content of the

effluent; if it is anaerobic, dilution by the receiving stream must be computed. Another factor is the B.O.D. load still carried in the effluent. Thus even a 90 per cent reduction of a 3,500 p.p.m. B.O.D. load would leave 350 p.p.m. of B.O.D. for the stream to oxidize. A large industry on a small stream would overload the stream. It appears, however, that lagooning the effluent following the treatment described may allow the development of a mixed biota sufficient to accomplish the final necessary reduction. The effluents of many waste treatment plants treating domestic sewage form streams with no dilution and in which fish thrive.

Conclusion

Apparently then, citrus waste can be treated biologically, provided certain routines are followed. These are:

1. Dilution of the waste to a maximum of 3,500 p.p.m. of B.O.D.
2. Treatment with lime to achieve a pH value of 9.0, followed by mechanical flocculation and removal of flocculated solids.
3. Careful control of processing plant wash up operations so that slugs of caustic are held in a receiving tank and discharged slowly into the effluent line. This caustic, however, is valuable *in small quantities* in aiding the maintenance of a high pH value.
4. Aeration for at least 6 hr., but preferably 8 hr.
5. Addition of 5 to 10 p.p.m. of phosphate and 30 to 50 p.p.m. of nitrate.
6. Finally, either putting the effluent through a trickling filter or lagooning it.

This process is not unduly expensive, and it is not a great deviation from standard practice. It requires careful control, however, and it has been successful on a laboratory and pilot plant scale. A good seeding from an activated sludge sewage treatment plant might be introduced initially into the aeration chamber.

Acknowledgment

Grateful appreciation is acknowledged for the courtesy of Dr. Wm. Bridge Cooke, Robert A. Taft Sanitary Engineering Center, USPHS, Cincinnati, Ohio, in identifying fungi isolated in these studies.

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METABOLISM OF AROMATIC COMPOUNDS BY ACTIVATED SLUDGE

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The stabilization of complex wastes from the chemical and the petroleum industries is becoming an ever-increasing problem. Many of these wastes contain aromatic compounds which, until a few years ago, were thought to be toxic to biological treatment systems. Yet, in spite of pressure from these industries for economical waste disposal systems, biological treatment is still being regarded as the final alternative after all physical and chemical treatment methods have been found uneconomical. The prime reason for the aversion of these industries to biological treatment of the wastes is the lack of information concerning the stability of the systems and the loads which can be applied safely.

The most common aromatic compound in industrial wastes is phenol. Because of the widespread use of phenol as a disinfectant, it has become a common criterion to exclude, if at all possible, from biological treatment units any wastes containing phenol or related aromatic compounds. Review of the literature shows that it has not been possible to exclude all phenolic wastes from biological treatment systems. In 1929, Mohlman (1) reported that ammonia still wastes (phenolic) could be satisfactorily treated with domestic sewage, provided the dilution was at least 1:19 by volume. At this same time, the Dow Chemical Company in Midland, Mich., was experimenting with trickling filtration for the treatment of its phenolic process wastes.

Harlow *et al.* (2) found that it was possible to obtain 90 per cent phenol removal from wastes containing 20 to 30 p.p.m. phenol. Eldridge (3) obtained 80 per cent phenol reduction for phenol wastes up to 80 p.p.m. on a shallow trickling filter but only 50 per cent removal at 120 p.p.m. phenol. Using a two-stage filter system he obtained complete removal of phenol in a synthetic waste containing 180 p.p.m. phenol. In 1952, Coe (4) reported on the treatment of refinery wastes containing 100 p.p.m. phenol by activated sludge with 90 to 95 per cent removal being obtained with 9 to 12 hr. aeration. The latest treatment plant for handling phenolic wastes is that of Imperial Oil at Sarnia, Ont., (5) where approximately 0.5 m.g.d. are handled by activated sludge and trickling filters. In spite of these studies, little is known about the stabilization of phenolic wastes by biological treatment systems.

Bacterial Metabolism

The bacteriologists first discovered bacteria which metabolized aromatic compounds in 1908 (6). Since that time many different species of bacteria have been isolated from the soil which could utilize the various aromatic compounds as their sole source of energy. Evans (7) became interested in how the bacteria broke down the ring structure and postulated a series of oxidative reactions from phenol to

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o-benzoquinone with a break in the ring and further oxidation to carbon dioxide and water. Stanier (8) devised the concept of simultaneous adaptation; *i.e.* bacterial adaptation to a single compound results in adaptation to all of the metabolic intermediates. With this concept, Stanier studied the metabolism of phenol by *Pseudomonas fluorescens* and set forth the currently accepted theory of phennol metabolism. That is—phenol is oxidized to catechol whereupon the ring splits and is further oxidized to beta-ketoadipic acid and then to succinic acid. The succinic acid enters the oxidative citric acid cycle where it is completely oxidized to carbon dioxide and water.

For the most part, the investigators of the practical aspects of the disposal of phenolic wastes have ignored the work of the pure bacteriologists even though they were both interested in the same problem, metabolism of aromatic compounds. The bacteriologists isolated many common soil bacteria which were capable of oxidizing phenol and related aromatics and cultured them in solutions having 0.1 to 0.5 per cent aromatics. These solutions were much stronger than those encountered in industrial wastes and the growth in them indicated a greater microbiological tolerance than has been obtained even at this date in waste treatment systems. This paper reports on: (a) how the engineer can use the bacteriologists' information to design experiments on the stabilization of pure aromatic compounds; (b) the interrelationships in the metabolism of the common aromatics; and (c) a detailed study of the metabolism of phenol.

Procedures

Activated sludge was used in these studies since it is by far the most efficient biological treatment system in practice today for industrial waste disposal. The activated sludge units were of the fill and draw type, each containing 1.5 l. of mixed liquor. Air was supplied through carborundum diffusers at a rate designed to keep the sludge in suspension. This quantity of air more than satisfied the biological demand for oxygen. Each unit was aerated for 23 hr., and settled for one hour. At that time one liter each of supernatant wastes and feed were added and aeration resumed. This operation simulated a continuous flow system having an aeration period of 23 hr. and complete sludge return.

Initially, the activated sludge units were started on a synthetic sewage of the following composition:

500	p.p.m. glucose
500	p.p.m. nutrient broth
1,000	p.p.m. potasium phosphate, dibasic
325	p.p.m. ammonium phosphate
50	p.p.m. sodium chloride
50	p.p.m. calcium chloride
50	p.p.m. magnesium sulfate
10	p.p.m. ferric chloride

The synthetic sewage was seeded with 100 ml. of settled sewage as the source of micro-organisms. After a satisfactory quantity of activated sludge had been built up and a clear supernatant produced, the systems were acclimated to the pure aromatic compounds.

The acclimation procedure consisted of adding 10 per cent of the final aromatic concentration to the desired unit and reducing the nutrient broth and glucose concentration by 10 per cent for two days and then increasing the aromatic concentration to 20 per cent for the next two days. This procedure was repeated until the activated sludge was being fed only the pure aromatic compound together with the inorganic nutrient salts. In all, 9 systems were acclimated to the following aromatics: phenol, o-cresol, m-cresol, p-cresol, benzyl alcohol, mandelic acid, anthranilic acid, benzoic acid, and catechol.

Results

In the initial study only seven acclimated systems were used; the benzoic acid and the catechol systems were

TABLE I.—Per Cent Theoretical Oxidation of 250 P.P.M. Aromatics by Acclimated Activated Sludges After 12 Hr. of Aeration[1]

Aromatics Fed	Activated Sludges Acclimated to Aromatics						
	Phenol	o-cresol	m-cresol	p-cresol	Benzyl Alcohol	Mandelic Acid	Anthranilic Acid
Phenol	39	34	37	20[2]	—	15[2]	20[2]
o-cresol	34	35	29	6[2]	—	9[2]	—
m-cresol	37	41	38	2[2]	—	13[2]	—
p-cresol	33	34	35	39	—	20[2]	—
Benzoate	37	31	37	37	37	37	37
p-OH benzoate	42	41	37	39	38[2]	—	44
Catechol	13	34	22	30	22	26	10
Benzaldehyde	38	—	—	—	30	—	35[2]
Benzyl alcohol	—	—	—	—	29	31	—
Mandelic acid	—	—	—	—	—	42	—
Anthranilic acid	—	—	—	—	—	—	50

[1] Corrected for endogenous metabolism and nitrification.
[2] Adaptive metabolism.

not started until the second phase of this investigation. The activated sludge units were acclimated to 500 p.p.m. of the aromatic compounds. After each system had been fed the desired compound for at least a week, Warburg studies were made to determine its ability to oxidize the aromatic compound being fed as well as other aromatics. It is impossible to present all of the results obtained in the Warburg studies and only the per cent theoretical oxidation of the aromatics after 12 hr. aeration is given in Table I. The concentration of aromatics used in the Warburg studies was 250 p.p.m., just one-half of the concentration used in the daily feed. The lower concentration was used to keep the total oxygen uptake in the Warburg from becoming too large, thereby preventing accurate readings.

The data show that phenol acclimated activated sludge was able to metabolize phenol, o-cresol, m-cresol, p-cresol, benzoic acid, p-hydroxybenzoic acid, and benzaldehyde to approximately the same extent in 12 hr., one-third of the theoretical oxidation, but catechol was metabolized only to 13 per cent. The Warburg data indicated that all these substrates were readily metabolized and yielded the same shape oxidation curve. Since these compounds are all structurally related, the similarity in oxidation is not unexpected. The o-cresol and m-cresol systems showed the same type of results as the phenol system. The p-cresol acclimated activated sludge did not act exactly as the other cresols. P-cresol activated sludge showed comparable results for p-cresol, benzoic acid, p-hydroxybenzoic acid, and catechol but showed adaptation to phenol, o-cresol and m-cresol. Up until the present time, it has not been possible to ascertain why the p-cresol acclimated sludge showed adaptive tendencies toward these latter compounds.

Benzyl alcohol acclimated sludge showed normal metabolism for benzaldehyde, benzoic acid, and catechol with adaptive metabolism for p-hydroxybenzoic acid. Considering the normal metabolism from alcohol to aldehyde to acid, the results are as expected. The adaptive tendency towards p-hydroxybenzoic acid points to the importance of substituted groups on the ring structure. The introduction of a hydroxy group in the para position slowed metabolism down until a biochemical modification could be made. Considering the extent of oxidation at 12 hr., it is obvious that this biochemi-

cal change was a minor one and was made very quickly. Mandelic acid is beta-hydroxyphenylacetic acid and is related metabolically to benzoic acid. The mandelic acid sludge rapidly metabolized benzyl alcohol, benzoic acid and catechol while showing adaptation to phenol, o-cresol, m-cresol and p-cresol. Anthranilic acid is o-aminobenzoic acid and its acclimated sludge showed normal metabolism for both benzoic acid and p-hydroxybenzoic acid. It showed adaptation to phenol and benzaldehyde, and slight utilization of catechol. The adaptive metabolism of benzaldehyde is natural since benzaldehyde is more reduced than benzoic acid and the biochemical reactions must be modified to handle the aldehyde oxidation. The mixed liquor suspended solids for these systems ranged from 320 p.p.m. for the phenol system to 5,740 p.p.m. for the p-cresol system.

Second Phase of Study

The second phase of this investigation dealt with three acclimated activated sludges: phenol, benzoic acid, and catechol. These sludges were acclimated to a daily feed of 500 p.p.m. in the same manner as the first series of units. Warburg studies were made on these sludges with 500 p.p.m. organic substrates rather than with 250 p.p.m. as in the first phase. The mixed liquor suspended solids were 5,230 p.p.m. for the phenol unit, 3,310 p.p.m. for the benzoic acid unit, and 6,640 p.p.m. for the catechol unit. Each acclimated sludge was tested as to its ability to metabolize phenol, catechol, resorcinol, hydroquinone, pyrogallol, benzoic acid and benzyl alcohol. The purpose of these runs was to determine if there were any apparent metabolic differences among the three systems. Phenol acclimated sludge rapidly metabolized all the substrates except hydroquinone. The benzoic acid acclimated sludge was also unable to metabolize hydroquinone and showed adaptation to benzaldehyde. The catechol system reacted like the phenol system except that it was able to adapt to hydroquinone. The data are shown in Table II. It was apparent that all three systems had only minor biochemical differences and that the oxidation of the various aromatic compounds followed similar metabolic pathways.

TABLE II.—Per Cent Theoretical Oxidation of 500 P.P.M. Aromatics by Acclimated Activated Sludges After 12 Hr. of Aeration[1]

Aromatic Fed	Activated Sludges Acclimated to Aromatics		
	Phenol	Benzoic Acid	Catechol
Phenol	32	34	35
Catechol	31	30	26
Resorcinol	33	34	39
Hydroquinone	3	4	25[2]
Pyrogallol	24	16	23
Benzoic acid	37	36	37
Benzyl alcohol	52	42[2]	43

[1] Corrected for endogenous metabolism.
[2] Adaptive metabolism.

Phenol Acclimated System

The results from the first two phases indicated that the ring structures studied were for the most part metabolized by the same general scheme with minor variations caused by variances in the chemical structure. In order to determine the reasons for the metabolic variations, it was decided that the general metabolic pattern of one of the systems would have to be thoroughly investigated. The phenol acclimated system was chosen primarily because of its importance in the industrial waste field. Carbohydrate metabolism was checked first. The per cent theoretical oxidation of 500 p.p.m. carbohydrates after 12 hr. aeration is shown in Table III. The data show that the phenol acclimated micro-organisms had the necessary enzyme systems to oxidize the simple pentose sugars as well as the simple

TABLE III.—Per Cent Theoretical Oxidation of 500 P.P.M. Carbohydrates by Phenol Acclimated Activated Sludge After 12 Hr. of Aeration

Carbohydrates	Theoretical Oxidation (%)
Glucose	21
Fructose	16
Sucrose	16
Arabinose	18
Xylose	19

hexose sugars. The per cent oxidations of the simple aliphatic organic acids and some of the citric acid cycle intermediates are shown in Table IV. All these compounds were rapidly metabolized indicating an ample concentration of beta-oxidation enzymes as well as the presence of a very active citric acid cycle.

The ability of phenol sludge to metabolize some of the common amino acids which make up the cellular protoplasm is shown in Table V. The enzyme concentration for oxidizing the amino acids was small and showed adaptation to all amino acids except methionine. Adaptation to the amino acids is natural since all of the enzymes connected with amino acid metabolism are related to the synthesis of protoplasm rather than oxidation of the amino acids. All of the enzymes whether synthetic or oxidative are reversible and interchangeable depending on the substrate and the end product. The sudden addition of a large quantity of amino acid to the system in the Warburg flask caused a partial reversal of the synthesis enzymes to oxidative enzymes. The enzymes concerned with the particular amino acid were stimulated and the biochemical reactions were directed to increasing these enzymes in order to obtain all of the energy that was present and available in the system. For this reason all of the enzymes showed adaptation, increasing the oxidation of the particular amino acid as the enzymes increased. The slow rate at which methionine was metabolized made it impossible to determine for certain if the system was adapting or was going to hold at a constant oxidation.

TABLE IV.—Per Cent Theoretical Oxidation of 500 P.P.M. Organic Acids by Phenol Acclimated Activated Sludge After 12 Hr. of Aeration

Organic Acids	Theoretical Oxidation (%)
Formic	66
Acetic	50
Propionic	40
Butyric	30
Heptanoic	27
Octanoic	20
Pyruvic	30
Citric	46
Succinic	57
Fumaric	41
Malic	46
Glycolic	32

TABLE V.—Per Cent Theoretical Oxidation of 500 P.P.M. Amino Acids by Phenol Acclimated Activated Sludge After 12 Hr. of Aeration

Amino Acid	Theoretical Oxidation[1] (%)
Glycine	58
Alanine	40
Valine	36
Leucine	24
Norleucine	20
Phenylalanine	24
Threonine	34
Glutamic Acid	38
Arginine	40
Histidine	13
Tryptophan	21
Hydroxyproline	36
Methionine	16

[1] Adaptive metabolism, except for methionine.

Oxidation of Aromatics

The oxidation of aromatic compounds related to phenol and benzene are shown in Table VI. The cresols were metabolized in the same manner as in the first phase of this investigation. The Warburg oxidation curves for the cresols are shown in Figure 1. The cresols follow phenol exactly

TABLE VI.—Per Cent Theoretical Oxidation of 500 P.P.M. Aromatics by Phenol Acclimated Activated Sludge After 12 Hr. of Aeration

Aromatics	Theoretical Oxidation (%)
Phenol	33
o-cresol	31
m-cresol	30
p-cresol	26
2,4 dimethylphenol	16
2,6 dimethylphenol	6
3,4 dimethylphenol	27
3,5 dimethylphenol	0
p-Amino benzoic acid	2[1]
Benzene	33[1]
Toluene	47[1]
Ethyl benzene	27[1]
n-Propylbenzene	10[1]
n-Butylbenzene	4[1]
s-Butylbenzene	1
t-Butylbenzene	1
s-Amylbenzene	1
t-Amylbenzene	1

[1] Adaptive metabolism.

in the initial stage of oxidation with p-cresol stopping at a slightly lower level than the other compounds. The dimethyl substituted phenols showed a pronounced effect on oxidation (Figure 2). The 3, 4 dimethylphenol was oxidized slightly less than phenol and the 2, 4 and 2, 6 and 3, 5 substituted phenols showed progressively less oxidation. All three of the latter compounds showed definite indications of a metabolic block or blocks. Figure 3 gives the oxidation curves for phenol, benzoic acid, benzyl alcohol, benzene and toluene. Phenol and benzoic acid followed identical oxidation while benzyl alcohol showed a slight adaptation in the oxidation of the alcoholic group to the carboxyl group. Benzene and toluene had to be adapted to before complete metabolism occurred.

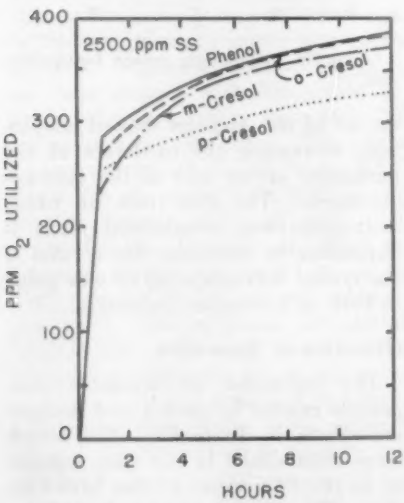

FIGURE 1.—Oxidation of 500 p.p.m. phenol and cresols by phenol acclimated activated sludge.

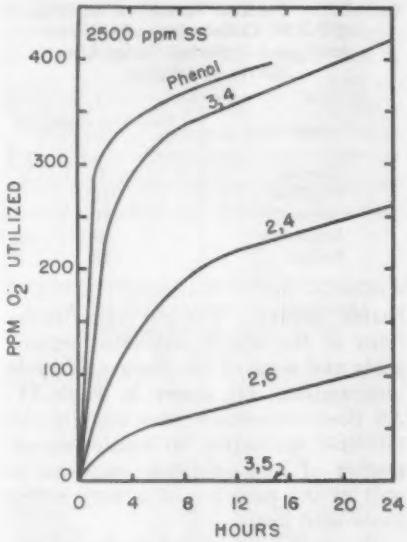

FIGURE 2.—Oxidation of 500 p.p.m. phenol and dimethylphenols by phenol acclimated activated sludge.

The rapid metabolism of the acidic compounds and the slower metabolism of neutral compounds pointed to a common pathway, beta-oxidation. If beta-oxidation were the prime biochemical reaction in phenol metabolism, the metabolism of the dihydroxyphenols should indicate comparable metabolism for phenol and resorcinol. Figure 4 shows the same oxidative pattern for phenol and resorcinol while

catechol followed a similar pathway half-way and then changed the rate of oxidation. Hydroquinone was only slightly oxidized before forming a metabolic block. Thus, it appeared that beta-oxidation was the major biochemical reaction in the metabolism of phenol and quite probably in other benzene ring compounds.

All the Warburg studies indicated that phenol was rapidly metabolized. Since the rate of oxidation and the rate of removal of phenol are of extreme importance in the design and

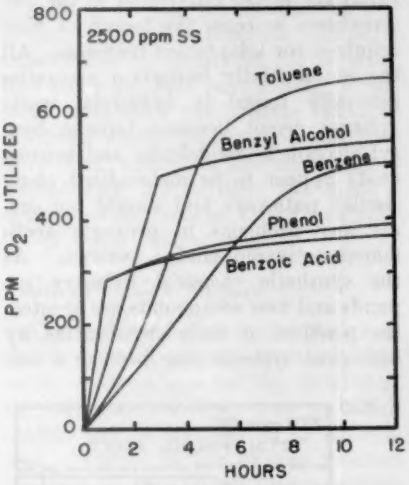

FIGURE 3.—Oxidation of 500 p.p.m. aromatic compounds by phenol acclimated activated sludge.

operation of industrial waste systems, a Warburg test was made with mixed liquor suspended solids of 5,200 p.p.m. and a feed of 500 p.p.m. phenol. The oxidation curve is shown in Figure 5 and the rate of oxygen uptake is shown in Figure 6. Both of these curves show extremely rapid oxidation. The initial oxidation was limited by the rate of oxygen transfer in the Warburg apparatus which is about four times as efficient as diffused aeration systems. Thus, it was obvious that the primary consideration in industrial

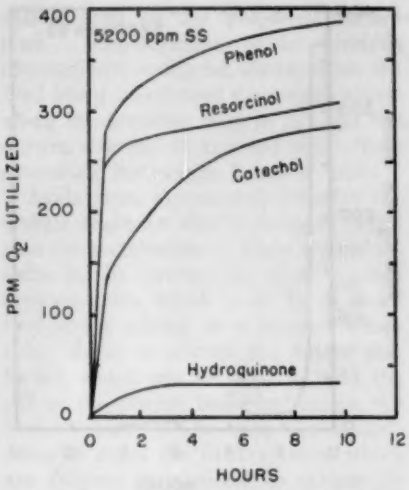

FIGURE 4.—Oxidation of 500 p.p.m. phenol and dihydroxyphenols by phenol acclimated activated sludge.

waste treatment plants handling phenolic wastes would not be one of toxicity but rather one of oxygen transfer.

Metabolic Balance

In order to determine the over-all metabolic balance of a system metabo-

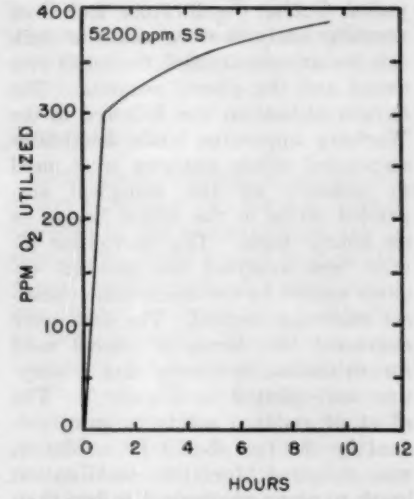

FIGURE 5.—Oxygen utilization for 500 p.p.m. phenol by phenol acclimated activated sludge.

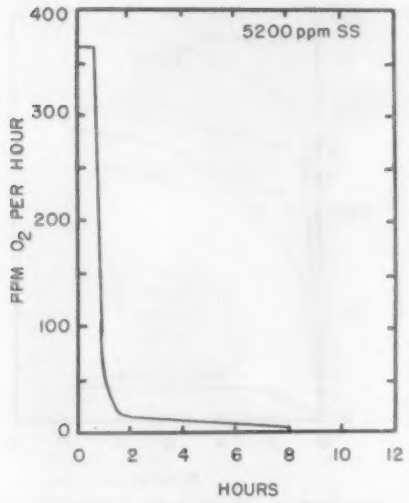

FIGURE 6.—Rate of oxygen utilization for 500 p.p.m. phenol by phenol acclimated activated sludge.

lizing phenol, wasting of mixed liquor suspended solids was started. One-third of the mixed liquor suspended solids was wasted daily with the suspended solids dropping rapidly to an equilibrium value of approximately 370 p.p.m. at the start of the aeration period. After equilibrium had been reached, analyses were made to indicate the oxygen utilized, the solids produced and the phenol removed. The oxygen utilization was followed in the Warburg apparatus while microfilter suspended solids analyses were used to measure all the biological suspended solids in the mixed liquor on an hourly basis. The microfilter filtrate was analyzed for residual organic matter by the dichromate chemical oxidation method. The data were converted into terms of phenol used for oxidation, synthesis, and adsorption and plotted in Figure 7. The effect of reduced solids is quite evident by the fact that 9 hr. oxidation was required for the stabilization break to occur as opposed to less than one hour at 5,200 p.p.m. mixed liquor suspended solids. The most important part of this run was the failure of phenol to show any toxic effects even though the quantity of solids was quite small by normal activated sludge standards.

Discussion

The stabilization of phenolic and related ringed compounds is primarily a function of the chemical structure of the compound and the compound on which the micro-organisms have been acclimated. As long as the aromatic compounds have similar structures acclimation to the new compound is rapid but as the differences in the two structures increase the length of time required for adaptation increases. All the commercially important aromatics generally found in industrial waste (phenol, cresol, benzene, toluene, benzyl alcohol, benzaldehyde, and benzoic acid) appear to be metabolized along similar pathways and should not create any problems in properly acclimated activated sludge systems. As the synthetic chemical industry expands and new compounds are created, the problem of their stabilization by biological systems may become a ma-

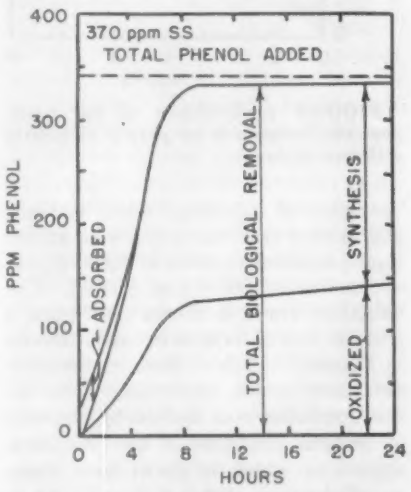

FIGURE 7.—Metabolic balance for the stabilization of phenol by acclimated activated sludge.

jor problem. Addition of side chains to the ring structure resulted in decreased metabolism as the length of the side chain increased. Addition of chemical groups on certain carbon atoms in the ring can result in metabolic blocks as in the case of the dimethylphenols.

One of the major problems facing the process engineer confronted with waste disposal problems of an unusual nature, such as these, is the lack of a proper understanding of bacterial physiology. Unfortunately, the bacteriologists themselves have not been interested in the metabolism of the unusual synthetic chemicals and little information is available. The work that has been done on bacterial physiology does show the general chemical reactions which the bacteria can produce and with this knowledge as a background, the engineer can make a reasonable estimate as to the treatability of waste components.

Limiting Design Factors

The limiting factor in the design of waste disposal systems treating aromatic compounds is not the toxicity of the compounds but the rate at which oxygen can be transferred to the system. Control of the oxygen demand can best be maintained by controlling the rate of feed by compartmental aeration or step-aeration. Both systems are well adapted to industrial waste treatment. Compartmental aeration consists of a series of small cubical aeration tanks, usually 10 ft. on a side, with an integral sedimentation tank from which the return sludge flows by gravity back into the aeration tank. The number of tanks in operation is dependent on the organic load, and as plant production changes with its resultant changes in waste loadings the tanks can be cut in or out. The simplicity of construction makes expansion of the treatment facilities easy and the design can be made for the present load rather than on the projected future load. Step-aeration tends towards conventional activated sludge with the feed being introduced at several points along the aeration tank to prevent the oxygen demand at any one point from exceeding the oxygen transfer rate.

Aside from the oxygen transfer the design engineer should keep in mind that the metabolism of these wastes results in the production of additional organic acids which must be neutralized if the system is to operate properly. Lime is one of the better materials which can be used to hold the pH in the proper biological range, 6.5 to 8.5. Lime reacts with the organic acids to form the neutral salts which are further metabolized to carbon dioxide and water with the calcium being released. The calcium and carbon dioxide undergo reaction to form calcium bicarbonate and calcium carbonate; the latter is insoluble and is readily incorporated into the activated sludge floc, adding to its weight and making it more readily settleable. Many of these wastes are deficient in essential nutrients such as nitrogen and phosphorus. If biological treatment is going to be effective these nutrients must be added in sufficient quantity to satisfy the biological demand.

Beta Oxidation

Although the concept of phenol oxidation of Stanier (8) has been widely accepted by the bacteriologists, the results of this study tended to show that phenol oxidation by activated sludge was related to fatty acid metabolism by beta-oxidation. The general equations for phenol oxidation are shown in Figure 8. The differences between the two schemes lies in the initial step of oxidation and the splitting of the ring. Use of the dimethylphenols permitted blocking of certain carbons for oxidation. The 2, 6 dimethylphenol blocked out the possibility of cate-

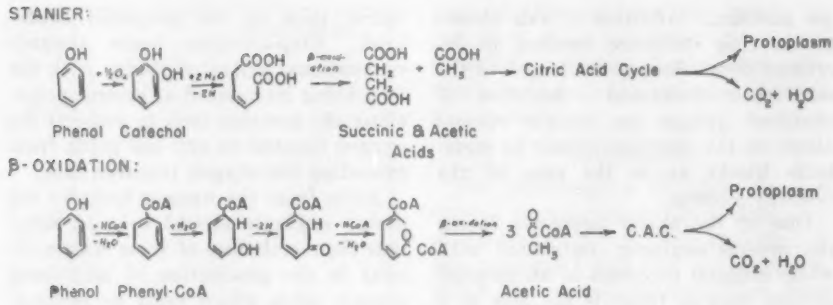

FIGURE 8.—General scheme of bacterial metabolism of phenol.

chol formation as postulated by Stanier but the phenol acclimated sludge showed partial oxidation of this compound indicating that catechol was not a required intermediate.

The rapid metabolic block on 2, 6 dimethylphenol indicated that an unnatural structure was formed after the initial oxidation. The 2, 4 dimethylphenol showed a similar metabolic block occurring further along the chain. Although the blocking structure has not been determined, it is believed to be related to the following group which occurs in the 2,4 and the 2, 6 but not in the 3, 4 dimethylphenols, —C(CoA):C(CH_3)—. The 3, 5 substituted phenol which would block beta-oxidation showed no metabolism. If catechol was the intermediate, the 3, 5 dimethylphenol would have shown partial oxidation. Thus, on this basis the oxidation of phenol is by beta-oxidation or a slight modification of the beta-oxidizing enzymes. The beta-oxidation scheme is further substantiated by the rapid rate at which the fatty acids were metabolized and by the comparative oxidation of catechol and resorcinol. Beta-oxidation is a common biochemical reaction occurring in the soil bacteria and its use in the stabilization of phenolic compounds helps to explain why it is possible to adapt activated sludge to these compounds so readily.

The large number of compounds, which can be immediately metabolized or rapidly adapted to points to the simplicity of the biochemical reactions occurring in these activated sludge systems. The ability of the microorganisms in the sludge to change substrate components is of the utmost value to industries where process changes are relatively frequent and abrupt. By understanding the mechanism of beta-oxidation and the natural metabolic scheme of the bacteria making up activated sludge, the process engineers can readily predict the ease and degree of metabolism of any new aromatic compound added to the system.

Conclusions

The results of this study on the oxidation of aromatic compounds by activated sludge has shown:

1. Activated sludge is quite well suited for treating phenolic and related aromatic compounds.
2. Phenol and other aromatics were not toxic to activated sludge in concentrations up to 500 p.p.m. phenol.
3. Oxidation of the aromatic compounds was limited by the rate of oxygen transfer.
4. Oxidation of the aromatic compounds was a function of the chemical structure of the compound.
5. Oxidation of the aromatic compounds appeared to be by beta-oxidation rather than by direct oxidation of the ring structure to catechol.

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SANITARY ENGINEERING RESEARCH GRANTS

A summary of research grants in sanitary engineering approved by the United States Public Health Service between July 1 and December 31, 1956, has recently been released. These grants, like all research grants of the USPHS, are administered through the Division of Research Grants, National Institutes of Health. Grants in the field of sanitary engineering are made on the recommendation of the Study Section on Sanitary Engineering and Occupational Health and are awarded primarily to universities and other research institutions.

Field	Number of Grants		Total
	New	Continuing	
Water pollution and treatment	10	14	$195,688
Sewage and industrial wastes	14	5	207,348
Community air pollution	7	5	322,480
Other sanitary engineering projects	5	2	86,920
Occupational health	3	2	63,978
Total	39	28	$876,414

There has been an encouraging increased interest in sanitary engineering research grants as evidenced by the growing number of applications now being received. Further information may be obtained from the Division of Sanitary Engineering Services, Public Health Service, U. S. Department of Health, Education, and Welfare, Washington 25, D. C.

BOUND WATER AND ACTIVATED SLUDGE BULKING *

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One of the distinguishing characteristics of gel systems is their ability to become highly hydrated. Sewage sludges have been classified as gels and perhaps the most important sludge, from the standpoint of water content and volume, is activated sludge. When it is realized that a good activated sludge will settle to a concentration of only one per cent solids, it becomes quite important to consider the nature and the relationships of the water associated with the sludge. Since bulky activated sludge is characterized by a large volume and poor settleability, the hydration or water-binding capacity of the bulky sludge acquires added significance.

Wilson (9) has called attention to the importance of the water relationships of the activated sludge. He recognized two different kinds of water, namely, interstitial water which can be forced out by the application of slight pressure, and adsorbed water which cannot be removed mechanically except by the application of enormous pressure. The relative amounts of these waters depend on the state of subdivision of the particles as well as the extent to which the jelly constituents are swollen with water.

The water in a gel may exist in part as liquid water with all its colligative properties, or as water bound by the colloid micelles with entirely different properties. This latter type of water has been referred to as "bound" water. The capacity of a gel to bind water is dependent upon the chemical, physical and electrical properties of the system. The phenomenon of water binding has been associated with the ability of the system to imbibe water and swell. Bloodgood (2) has stated that one of the causes of bulking of activated sludge might be due to swelling of the zoogleal masses. Greeley (6) and Pearse (7) reviewed a number of causes and cures suggested for the phenomenon of bulking.

The purpose of this paper is to determine whether there is a relationship between bulking, bound water content and the biochemical characteristics of activated sludge.

Analysis of Bound Water

The dilatometric method was selected for the measurement of bound water (3)(4)(5). This method is based on the theory that bound water does not freeze at temperatures below the freezing point temperature of free water. If the total water and free water are known, then the difference between them is calculated as the bound water. The total water was determined by drying a sample of activated sludge at 105° C. for 24 hr. and the free water was determined by noting the expansion caused by freezing the sludge. By correcting the expansion caused by the water-ice transformation to its free water equivalent, the bound water was calculated.

Laboratory Apparatus

A diagram representative of the dilatometers used in these experiments is shown in Figure 1. The apparatus consists of a glass unit composed of

* Paper of the Journal Series, New Jersey Agricultural Experiment Station, Rutgers University.

two separate sections which can be joined by means of a ground glass joint. The bottom section measures approximately 2 in. in diameter and 4-in. deep, with a capacity of 45 to 65 ml. A small bore glass tube about 12 in. in height is fused to the top of the upper section. Total volume is 2 to 3 ml. calibrated into increments of 0.01 ml.

The liquid used to measure the contractions and expansions during the freezing of the sludge was a crude petroleum. The selection of this indicator liquid was based on its immiscibility with water, a specific gravity less than water, and the fact that it is not subject to solidification at the lowest temperatures employed in the experiments (− 20° C.).

The sludges were frozen by immersing the dilatometers into a freezing bath consisting of ethanol and dry ice. The temperature of the bath could be lowered and regulated by introducing a piece of dry ice into the ethanol with a metal prong.

Since it was not possible to fuse thermometers into the dilatometers, the temperature of the units during the freezing operation was obtained by means of a "dummy," consisting of a bottom section of a dilatometer containing sludge and petroleum. Into this "dummy" sample was inserted a rubber stopper containing a thermometer. The temperature of this sludge-petroleum mixture was taken to represent the temperature of the systems being examined. The thermometer was a mercury type calibrated to 0.1 of a degree.

Laboratory Procedure

A weighed amount of sludge was introduced into the bottom section of the dilatometer containing 15 ml. petroleum. The dilatometer was stoppered after weighing in order to prevent evaporation. Another portion of the sludge was weighed and dried for the total solids determination. The

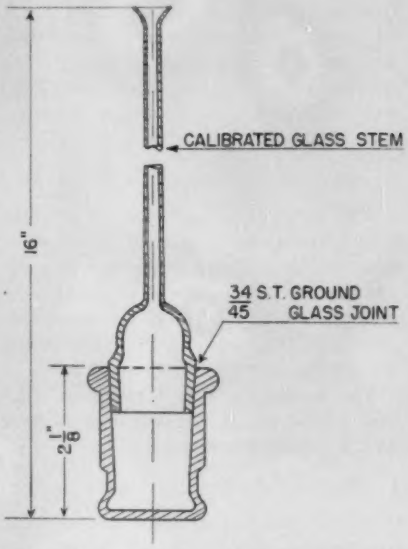

FIGURE 1.—Dilatometer for bound water determinations of aerated sludge.

top section of the dilatometers was inserted after removal of the stopper. The ground glass joint was lubricated with silicone and the two sections fastened together with springs attached to glass spurs on the top and bottom sections. With the unit assembled, petroleum was added by means of a 50-ml. burette through the open end of the calibrated glass stem. The petroleum was added until the entire unit was filled to the zero mark on the glass stem. The amount of petroleum needed to fill the dilatometer was recorded.

The filled dilatometer was then immersed in the ethanol solution which completely covered the dilatometer. Then the dry ice was added, and at various temperatures the level of the petroleum in the glass stem was recorded. The readings were taken 5 min. after a specific temperature was reached to insure equilibrium at that temperature. When freezing began, the system was allowed to expand with a minimum of ice addition until the expansion of sludge ceased. This

freezing process required about 35 to 45 min. The temperature was then lowered, and the contractions of the system after freezing was completed were recorded. The final low temperature was − 20° C.

Calculations

The method of calculation of free water from the expansion of ice as adopted in these experiments was dependent upon the behavior of the petroleum on exposure to low temperature and the volume increase when one gram of water freezes to ice.

The necessary data for this calculation are a standard petroleum curve and a petroleum-water curve.

1. Standard Petroleum Curve

The liquid employed to measure the contraction and expansion during the freezing was a crude petroleum. Any indicator may be used provided it is: (a) immiscible with water; (b) has a specific gravity less than water; (c) does not solidify at the lowest temperature employed; and (d) has a linear contraction throughout the temperature range.

The standard petroleum curve is obtained by filling the dilatometer with a known amount of petroleum, noting the temperature and stem reading, and determining the contraction upon lowering the temperature to − 20° C. If the contraction is linear, then the contraction curve of a standard amount of petroleum can be calculated and plotted. The contraction curve for 50 ml. of petroleum is represented by line AB in Figure 2.

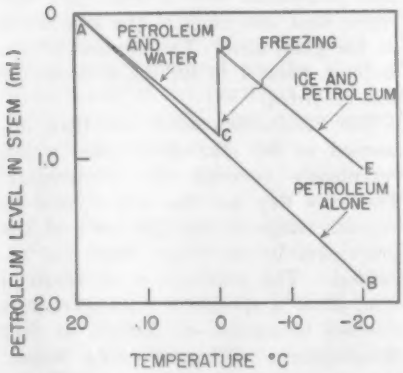

FIGURE 2.—Typical volume-temperature relationships of petroleum and petroleum-water mixtures.

2. Petroleum-Water Curve

The same procedure was used for the derivation of the standard petroleum-water curve except that a known amount of distilled water is added to the petroleum. The resulting typical curve is shown in Figure 2 as line ACDE.

3. Method of Calculation of Free Water Expansion

The method of calculation can be illustrated best by an example.

(a) 50 ml. petroleum at 20° C. = 0.00 ml. stem reading.
(b) 50 ml. petroleum at − 20° C. = 1.94 ml. stem reading.
(c) 45 ml. petroleum + 5 ml. water = 1.24 ml. stem reading.
(d) Since the contraction is linear, the 45 ml. petroleum would have contracted to $45/50 \times 1.94 = 1.74$ ml.
(e) Since the reading is 1.24 ml., the difference, $1.74 - 1.24 = 0.50$ ml. = expansion due to 5 ml. water.
(f) $0.50/5 = 0.10$ ml. expansion per milliliter of water.

After deriving the petroleum standard curve and the expansion of one milliliter of water when frozen, the free water of the sludge can be calculated.

Example:

Assume 15 gm. sludge + 43 ml. petroleum is subjected to freezing.

Total solids = 10 per cent. Thus, 1.5 gm. = dry solids and 13.5 gm. = total water.

Upon freezing to $-20°$ C., the stem reading is 0.76 ml.

The petroleum level is $43/50 \times 1.94 = 1.66$ ml.

The difference due to water expansion $= 1.66 - 0.76$ ml. $= 0.90$ ml.

Since 1 ml. water expands 0.1 ml. upon freezing, a 0.90 ml. expansion represents $\frac{0.90 \text{ ml.}}{0.1 \text{ ml./ml.}} = 9$ ml. free water.

Total water − free water = bound water. 13.5 ml. − 9 ml. = 4.5 ml. water.

$$\frac{4.5 \text{ ml. bound water}}{1.5 \text{ gm. dry solids}} = \frac{3 \text{ ml. bound water}}{1 \text{ gm. dry solids}}$$

= 300 per cent bound water.

Experimental Results

The bound water content and sludge volume index of mixed liquors from a number of sewage treatment plants were determined to establish whether any relationship existed between them. The results (Table I) show that a sludge with a low volume index has a low percentage of bound water (90 to 100 per cent), and a sludge with a high volume index has a high bound water content (380 per cent).

Continuous Aeration of Bulky Sludge

The relationship would be firmer and more convincing if the sludge volume index of a given sludge could be made to vary with a simultaneous change in the bound water content. Starting with a bulky sludge, when the volume index is decreased the bound water content should decrease, and starting with a sludge of a low volume index, when it is induced to bulk, the bound water content should increase. A number of experiments were run using both methods of approach.

TABLE I.—Comparison of Bound Water in Bulky and Non-Bulky Sludges

Sludge Source	Bound Water (% of vol. sol.)	Sludge Volume Index
A	380	400
B	106	112
C	90	60

TABLE II.—Effect of Continuous Aeration Without Feed of a Bulky Sludge on Bound Water and Sludge Volume Index

Aeration Period (days)	Bound Water (% of vol. sol.)	Sludge Volume Index
1	363	400
6	148	85
12	59	62

Table II gives the results of an experiment on the effect of continuous aeration without feeding, of an initially zoogleal type of bulky activated sludge, on the sludge volume index and the bound water content. It is apparent that good correlation exists between the decrease in sludge volume index and the bound water content. During six days of aeration, the sludge volume index decreased from 400 to 85 and the bound water content from 363 to 148 per cent. It should be noted that the decrease in sludge volume index is more rapid initially than the decrease in the bound water.

Additional decreases in both sludge volume index and bound water content took place with aeration periods as long as 12 days. Simultaneous with these changes the color of the sludge changed from grey to golden brown. Microscopic examination of the floc also revealed a change in appearance. The original sludge consisted of almost transparent, lobed, irregular-shaped zoogleal floc. Sphaerotilus was not present in significant numbers. After six days of aeration the zoogleal colonies became dense and opaque.

The above experiment was repeated in a similar manner except that some additional determinations of sludge oxygen demand, solids and nitrates were made. A zoogleal type of bulky sludge was aerated continuously with-

TABLE III.—Effect of Continuous Aeration Without Feed of a Bulky Sludge on Bound Water, Sludge Volume Index, Solids and Nitrates

Aeration Period (days)	Susp. Solids (p.p.m.)	Volatile Solids (%)	Bound Water (% of vol. sol.)	Sludge Volume (%)	Sludge Volume Index	Nitrate (p.p.m.)	Oxygen Utilized*
0	2720	85.1	380	98.5	360	0.65	—
1	2690	83.5	370	96.0	370	0.62	6.9
2	2300	82.0	338	92.0	400	0.73	7.1
3	2010	81.3	—	86.0	426	—	6.8
4	1870	80.0	320	72.0	380	—	6.8
5	1770	78.6	230	50.0	282	0.73	4.2
6	1700	77.6	155	20.5	120	0.73	2.6

* $\frac{\text{milligram oxygen utilized per hour}}{\text{gram volatile solids}}$.

out feeding for six days. The results of the various determinations are given in Table III. It can be seen that the sludge volume index during the first three days of aeration did not change materially. In fact, if anything, the sludge volume index increased somewhat (from 360 to 425), which was attributed to the fact that the sludge was allowed to concentrate in the laboratory and the supernatant decanted before its use in the experiment. When the original sludge was diluted with water to one-third of its original concentration, it settled to only 90 per cent of its volume in 30 min. with an indicated sludge volume index of 1,080 or greater. Thus the sludge volume index is not applicable to a sludge which does not settle. Hence, such sludges should be diluted either to a given suspended solids concentration (say 1,000 p.p.m.) before the determination of sludge volume index or they should be diluted so that they settle to a volume of not more than for example 75 per cent.

The first significant sludge volume index value was obtained on the fourth day for at this time a dilution of the sludge resulted in a corresponding decrease in the sludge volume. It is fair to state, therefore, that the sludge volume index decreased from some high indeterminate value to 380 after four days of aeration. The bound water content during this period decreased from 380 to 320 per cent.

The results of these two experiments agree in that the sludge volume index decreased at a greater rate initially than the bound water content. Between the fourth and sixth days both the sludge volume index and the bound water content decreased materially. Simultaneously with these changes in the bound water content and sludge volume index, brought about by continuous aeration without feeding, the suspended solids content and percentage volatile solids of the mixed liquor decreased, indicating decomposition of the organic matter in the sludge. It is to be observed, also, that the nitrate content of the sludge originally was not high and that even after six days of continuous aeration the sludge was not converted to a nitrifying sludge. The microscopic appearance of the sludge underwent a change similar to that of the previous experiment, namely a change from a diffused and highly indented floc to a dense and more regular-edged floc. Sphaerotilus was not present in significant numbers, either in the initial sludge or after subsequent aeration.

The oxygen demand of the unit amount of the sludge as measured by the Warburg respirometer did not change materially during four days in the respirometer, but decreased significantly during the fifth and sixth days. This indicates that although during the first four days of aeration the sludge was being oxidized and solids

were being destroyed, the remaining volatile solids had practically the same oxygen demand per unit amount of volatile solids as the initial sludge. Only after the fourth day did the nature of the material being oxidized change as indicated by the lesser amount of oxygen utilized per unit amount of volatile solids remaining. This was also the period when the sludge volume index and bound water content underwent an abrupt change. It may represent the oxidation of less readily available and more complex materials of protoplasmic origin rather than the oxidation of the more available sewage impurities originally contained in the sludge.

The preceding experiments proved that as the sludge volume index of a zoogleal type of bulky sludge decreased the bound water content also decreased with continuous aeration without feeding. It was of interest, therefore, to establish a similar relationship starting with a nonbulky sludge and inducing it to bulk.

Plant-Scale Study with Unchlorinated Returned Sludge

The first experiment was made on a plant-scale basis. Previous experience at an institutional sewage treatment plant had shown that when chlorination of returned sludge was stopped the sludge volume index increased gradually. This chlorination practice was stopped and no other changes in the operation of the treatment plant were introduced. The results of this experiment are given in Table IV. The sludge volume index increased from 43 to 200 in 9 days of operation without chlorination, and the bound water content increased from 107 to 198 per cent during the same period. There was a slight increase in the per cent volatile solids of the sludge. Nitrates which were high during the period of chlorination of the sludge were not affected by the cessation of chlorination. The D.O. content of the mixed liquor, which was 0.8 p.p.m. at the beginning of the experiment, showed a significant increase towards the end of the test period. These results in respect to dissolved oxygen content indicate the following: (a) that the effect of chlorination is not due to the decrease in the biological utilization of oxygen resulting in an increase in the D.O. content and (b) that sludge bulking is not due to an oxygen deficiency.

The microscopic appearance of the sludge changed during this period from the dense floc particles in the original sludge to a diffuse and irregular-shaped floc. There was no overgrowth of Sphaerotilus.

TABLE IV.—Changes in Sludge Characteristics After Cessation of Chlorination

Days After Cessation of Chlorination	Sludge Volume Index	Bound Water (% of vol. sol.)	Nitrates[1] (p.p.m.)	D.O.[1] (p.p.m.)
0	43	107	11.0	0.8
1	50	106	11.3	0.7
2	59	—	—	0.9
3	58	—	10.2	1.2
4	78	—	—	0.7
7	138	157	10.1	1.5
8	176	177	9.6	2.2
9	200	198	10.0	3.0

[1] Mixed liquor at the effluent end of the aeration tank.

Sludge Chlorination

In order to show whether the effect of chlorine on sludge volume index is physical or biological, various quantities of chlorine were added to a sample of bulky sludge and allowed to settle for one-half hour; the sludge volume index and bound water were then determined. Since the sludge was neither fed nor aerated, it is not possible to attribute the effect to biochemical reactions. The results (Table V) show that the treatment of sludge with only one dose of 10 p.p.m. chlorine reduced the sludge volume index from 177 to 120 and the bound water from 189 to 100 per cent. With larger doses of chlorine the effects were

TABLE V.—Effect of Chlorination on Bound Water and Sludge Index

Chlorine Dosage (p.p.m.)	Sludge Volume Index	Bound Water, (% of vol. sol.)
0	177	189
10[1]	120	100
100	105	—
200	83	60
500	83	57

[1] 0.6 per cent on the basis of sludge solids.

more pronounced. It is reasonable to expect that in a sewage treatment plant with a sludge age of three to four days, a given sludge would be subjected to repeated dosages of chlorine before it is finally wasted.

The action of chlorine in the sludge appears then to be purely physical in releasing a part of the bound water and thereby decreasing the sludge volume index. In a treatment plant where chlorine is being applied continuously, the effect of chlorine is that of combating the tendency for the sludge volume index to increase by continuously releasing the excessive amount of bound water and keeping it in check as long as chlorine is applied. Once chlorination is stopped the sludge will gradually tend to bulk.

Laboratory Studies with Various Sludge Loadings

The final experiment was made to induce sludge to bulk under controlled laboratory conditions. For this experiment, the sludge was aerated and agitated by paddles on a laboratory flocculator. The speed and the level of the paddles in the sludge could be regulated to maintain dissolved oxygen in the mixed liquor at all times. The paddle speed was 170 r.p.m., and the D.O. content was always maintained between 1 and 3 p.p.m. not only to insure aerobic conditions but to simulate actual treatment plant D.O. levels. The dissolved oxygen was determined by the polarograph and the time lapse between securing the sample and the determination was about 10 sec.

The sludge was fed a soluble-colloidal fraction and a settleable fraction of sewage. The soluble-colloidal fraction was obtained by super centrifugation of settled sewage. The settleable fraction was collected and resuspended in mineral dilution water. The purpose of this experiment was to feed the sludges with a feed of known B.O.D. strength in order to determine the sludge load. It was, thus, impractical to feed a sewage (or its fractions) which was collected daily, because its B.O.D. would vary from day to day. In order to overcome this difficulty, large quantities of a particular sewage were collected, separated into settleable and soluble-colloidal fractions, autoclaved, and stored.

The sludges were fed four times daily; 9 AM, 1 PM, 5 PM, and 9 PM. The concentrations of the feeds were adjusted to maintain sludge loadings of 1, 0.5, and 0.33 lb. of B.O.D. for both fractions. The sludge solids were kept at 800 p.p.m. volatile solids by making daily determinations of the solids content and wasting the necessary amount of sludge.

The sludge volume index, bound water and the oxygen demand characteristics of the original sludge and the aerated sludge after six days of feeding with the two types of substrates at different sludge loading rates are given in Table VI.

The greatest increase in the sludge volume index and bound water was observed when the soluble-colloidal fraction was fed at the rate of 0.5 lb. of B.O.D. per pound mixed liquor solids. The same fraction fed at a sludge loading rate of 1 lb. of B.O.D. did not show as great an increase in sludge volume index or bound water. At a sludge loading factor of 0.33 lb. of B.O.D. the sludge volume index and bound water after six days of feeding were practically the same as in the original sludge. The color of the mix-

TABLE VI.—Effect of Feeding Colloidal-Soluble and Settleable Fractions of Sewage on Activated Sludge Characteristics

Type of Feed	Sludge Loading[1]	Sludge Volume Index	Bound Water (% of vol. sol.)	Oxidation Constant "k"	"L"[3]	Oxygen Utilized[2]
Initial sludge		90	110	0.108	478	4.0
Soluble-colloidal[4]						
A	1	250	262	0.218	625	10.04
B	0.5	380	332	0.250	650	11.3
C	0.33	78	116	0.131	470	4.1
Settleable[4]						
A	1	78	81	0.132	830	7.5
B	0.5	80	85	—	—	—
C	0.33	80	84	0.160	468	5.4

[1] Sludge loading = $\frac{\text{pounds of B.O.D. fed per day}}{\text{pounds of settleable solids in mixed liquor}}$.

[2] Milligrams of oxygen per gram of volatile solids.

[3] Average milligrams per 1,000 p.p.m. volatile solids per hour over 24-hr. period.

[4] After six days of feeding.

ture fed with the soluble-colloidal fraction at a sludge loading factor of one changed to greyish, with a turbid supernatant containing 45 p.p.m. B.O.D. Microscopically the floc had a diffuse, transparent irregular-edged appearance with no evidence of increase in *Sphaerotilus* growth. The mixture fed with the soluble-colloidal fraction at a sludge loading factor of 0.5 gave a sparkling effluent with a B.O.D. of 10 p.p.m., but microscopically it had the same appearance as the sludge fed at a loading factor of one. The soluble-colloidal fraction fed at a loading factor of 0.33 retained its golden brown appearance, had a supernatant B.O.D. of 10 p.p.m., and was composed of dense zoogleal colonies.

The oxidation characteristics of the sludge at the end of the six-day feeding period as determined by the Warburg method indicate that at a loading factor of 0.5 the sludge had the highest oxidation rate, with the sludge loading factor of one producing nearly the same rate. The sludge loaded at 0.33 lb. of B.O.D. per pound of mixed liquor solids had the same characteristic oxidation rate at the end of the six-day feeding period as the original sludge.

When the settleable fraction was used as a substrate neither the sludge volume index nor the bound water changed at any of the loading rates employed. The sludges settled well with a clear supernatant (10 p.p.m. B.O.D.) but became perceptibly darker with repeated feelings. Microscopically, zoogleal flocs decreased and were replaced by amorphous particles. Oxidation characteristics of these sludges at the end of the feeding period were somewhat higher than those in the original sludge.

Sludge Accumulation

Results on sludge accumulation from this experiment are given in Table VII. With the soluble-colloidal fraction used as a substrate the greatest absolute increase in suspended solids was with a loading factor of one, but the increase, expressed as a percentage of the B.O.D. fed, was lower than with the loading rate of 0.5. It should be remembered, however, that not all the B.O.D. in the former loading rate was being removed. Therefore, the differences in the two loading rates, expressed as percentage increase of solids on the basis of the B.O.D. removed, would probably be closer to each other than is indicated by the values given on the basis of B.O.D. fed. The smallest absolute increase in suspended sol-

TABLE VII.—Effect of Sludge Loading and Type of Feed on Sludge Accumulation

Type of Feed	Sludge Loading	B.O.D. Fed per Day (p.p.m.)	Suspended Solids		Increase in Sludge Solids	
			Fed per Day (p.p.m.)	Increase Per Day	Per Cent of B.O.D. Fed	Per Cent of Susp. Sol. Fed
Soluble colloidal						
A	1	800	0	293	37.6	—
B	0.5	400	0	202	50.0	—
C	0.33	260	0	53	21.8	—
Settleable						
A	1	800	515	407	50.9	79
B	0.5	400	257	183	45.6	71.2
C	0.33	260	172	85	32.8	49.5

ids and the percentage increase in suspended solids on the basis of B.O.D. fed was with the loading factor of 0.33. It appears from these results that the greater the sludge loading with the soluble-colloidal fraction, the greater the amount of sludge accumulation and a greater percentage of the B.O.D. fed is converted to sludge.

With the settleable fraction used as substrate, both the absolute increase in sludge solids as well as the increase expressed as either a percentage of B.O.D. or suspended solids fed were greater with an increasing loading factor. It appears that the absolute increase in sludge is greater with an equivalent quantity of B.O.D. fed in the settleable fraction than with the soluble-colloidal fraction for corresponding loading factors. Between 70 and 80 per cent of the suspended solids fed is recovered as sludge with loading factors of 0.5 and 1.0, and 50 per cent with a loading factor of 0.33.

With the soluble-colloidal fraction used as a substrate, the accumulation of sludge can only be ascribed to protoplasmic growth by assimilation and conversion of food materials in the substrate to cellular substance. With the settleable solids used as a substrate, sludge accumulation can be the result of: (a) simply the transference of suspended matter from the liquid phase to the sludge; (b) the oxidation of the adsorbed material giving rise to protoplasmic growth; or (c) some variable combination of these two processes. With the data on hand, it is not possible to differentiate and evaluate the relative parts played by these two forces. It can definitely be stated, however, that the sludge increase cannot be attributed completely to the protoplasmic growth as in the case of the soluble-colloidal fraction. With the settleable fraction the accumulation of sludge is believed to be caused primarily by adsorption followed by a slow rate of biological utilization and transformation of a small part of the settleable solids fed to protoplasmic material.

Volatile Matter and Nitrogen Content

Table VIII presents the values of percentage of volatile solids and percentage of nitrogen in the sludges fed

TABLE VIII.—Effect of Sludge Loading and Type of Feed on Volatile Matter and Nitrogen Content of the Sludge

Type of Feed	Sludge Loading	Volatile Matter (%)	Organ. N Dry Basis (%)
Initial	—	83.6	6.3
Soluble-colloidal[1]			
A	1	87.2	7.9
B	0.5	87.5	7.8
C	0.33	84.4	—
Settleable[1]			
A	1	80.3	5.6
B	0.5	81.1	6.1
C	0.33	80.7	5.8

[1] After 6 days of feeding.

for six days at different loadings with different fractions of sewage.

The volatile solids in the sludge increased from an initial value of 83.6 per cent to slightly more than 87 per cent, after feeding the soluble-colloidal fraction for six days at loading rates of 1 and 0.5. At a loading rate of 0.33 there was only a very slight increase over the original volatile matter content of the sludge.

Similarly, the nitrogen content of the sludge increased from an initial value of 6.3 per cent on the basis of dry solids to 7.8 or 7.9 per cent with loading factors of 1 and 0.5. Unfortunately, the value for the loading factor of 0.33 is not available. The percentage of volatile matter in the soluble-colloidal fraction fed was 51.5 per cent. This probably does not represent the actual organic matter content because inorganic matter such as bicarbonates are also volatilized on ignition. The actual volatile matter content should be less than 51.5 per cent. The sludge formed has, therefore, a higher percentage of organic matter than the substrate fed.

The sludges fed with the settleable fraction produced sludges with somewhat smaller volatile matter content than the initial sludge (80 to 81 per cent as compared with 83.6 per cent). In addition, they also had less of a volatile matter content than the sludges fed with the soluble-colloidal fraction. The volatile matter content of the settleable solids fed was 77.8 per cent. The sludges formed, therefore, had a volatile matter content intermediate to that of the initial sludge and of the solids fed. The sludges produced by feeding the settleable fraction had nitrogen contents lower than the initial sludge and also lower than the sludges produced by feeding the soluble-colloidal fraction.

Oxygen Utilization

The oxygen utilization rates of the original sludge and of the sludges produced after feeding with the soluble-colloidal fraction for three and six days and with the settleable fraction for six days at various loadings are given in Table IX. These values were obtained with the Warburg apparatus over a 44-hr. period. It will be seen that the basal sludge-oxygen utilization increased from a value of 5 p.p.m. per 1,000 p.p.m. of sludge per hour to a value of 8.4 p.p.m. after three days of feeding and to 9.1 p.p.m. after six days of feeding at a sludge loading factor of one. At a sludge loading factor of 0.5, the corresponding values were 8.9 and 9.6 p.p.m. after three- and six-day feeding periods, respectively. At a loading factor of 0.33, the oxygen utilization rate after three and six days of feeding was 4.6 p.p.m., a value somewhat lower than the oxygen utilization of the original sludge. The oxygen utilization of the sludge produced by feeding the settleable fraction for six days was 8.3 p.p.m. at a loading factor of one and 5.3 p.p.m. at a loading factor of 0.5. It is apparent that the original sludge-oxygen utilization characteristics were maintained only with a loading factor of 0.33 for the soluble-colloidal fraction and a loading factor of 0.5 for the settleable fraction. At higher loading rates the oxygen utilization of the sludge became greater.

To sum up the results of this experi-

TABLE IX.—Effect of Sludge Loading on the Oxygen Utilization of Sludge[1]

	Sludge Loading[2]			
Original sludge	5.0	1	0.5	0.33
After 3 days feeding of soluble-colloidal fraction	—	8.4	8.9	4.6
After 6 days feeding of soluble-colloidal fraction	—	9.1	9.6	4.6
After 6 days feeding of settleable fraction	—	8.3	5.3	—

[1] Parts per million of oxygen utilized per 1,000 p.p.m. of unfed sludge per hour during 44 hr. in the Warburg.

[2] Pounds of B.O.D. fed per pound of sludge solids.

ment at a loading factor of 0.33 with soluble-colloidal fraction, the sludge volume index, bound water and oxygen utilization of the sludge did not show a material difference when compared with the initial sludge. Sludge accumulation was lowest at this loading. At a loading factor of 0.5, occurred the maximum increase in sludge volume index, bound water, sludge oxygen demand, sludge accumulation per unit amount of food material, and nitrogen content of the sludge. At a sludge loading factor of one, none of these parameters was as high as with a sludge loading factor of 0.5. The response to the feeding of the settleable fraction was somewhat anomalous in that it did not bulk; nor did the bound water content increase at any loading factor. The settleable fraction cannot be considered as a typical activated sludge, but should be considered as aerated solids.

Sphaerotilus-Bulked Sludge

The work so far reported was concerned with the zoogleal type of sludges. In order to determine whether there was any relationship between bound water and the sludge volume index of a bulky sludge composed primarily of *Sphaerotilus*, bulking was produced in the laboratory by the addition of glucose to sludge under aeration. The sludge was fed, batchwise, three times per day. After each aeration period the sludge was settled, the supernatant was siphoned off, and glucose and urea, as a nitrogen source, were added to the sludge with a synthetic B.O.D. dilution water. The carbon-nitrogen ratio employed was 20:1.

Table X illustrates the effect of the sugar additions. The initial sludge was dosed with 600 p.p.m. glucose three times each day for a period of two days. The solids increased from 2,610 p.p.m. to 3,065 p.p.m., but there was no change in the sludge volume index or the bound water. Microscopically, there were no significant numbers of *Sphaerotilus*. At this point the sludge solids were reduced to 1,533 p.p.m. by wasting sludge, but the glucose concentration added was maintained at 600 p.p.m. Under these conditions the sludge became progressively worse in its settleability, and on the third day the sludge did not settle at all. The sludge volume index rose from 52 to 385, and the suspended solids increased from 1,533 p.p.m. to 2,624 p.p.m. The bound water, however, did not increase, since it remained essentially the same, varying from 98 to 113 per cent. The sludge was composed almost entirely of *Sphaerotilus* and had changed to a pale straw color. White "balls" of *Sphaerotilus* were evident, macroscopically, on the second day, and were in great abundance at the end of the third day.

The Sphaerotilus-bulked sludge was not similar to the zoogleal type of bulky sludge in respect to the bound water changes. The zoogleal sludge increased its bound water content with an increase in the sludge volume index, while the bound water of the Sphaero-

TABLE X.—Effect of Feeding Activated Sludge with Glucose on Sludge Characteristics

Period	Glucose Added (p.p.m.)	Feedings (no.)	Suspended Solids (p.p.m.)		Sludge Volume Index		Bound Water[1] (% of vol. sol.)	NO_3 (p.p.m.)
			Initial	Final	Initial	Final		
1	600	6	2610	3065	50	52	113	5.2
2	600	9	1530	2624	52	385	98	4.3
3	0	0[2]	2624	1875	385	71	58	12.2

[1] Initial bound water of sludge was 110 per cent.
[2] Continuous aeration for 8 days without feeding.

tilus sludge remained rather constant. This would suggest a fundamental physical difference between the two bulky sludges. Another difference was the effect of dilution on the volume settled. The zoogleal sludge did not settle upon dilution to any significantly lesser volume, whereas the Sphaerotilus sludge was reduced in volume almost proportionately to its solids content.

After the bulky stage was reached, the sludge was aerated in an effort to reduce its sludge volume index. It required 8 days of continuous aeration to decrease the index from 385 to 71. During this period, the solids concentration was reduced from 2,674 p.p.m., with 91 per cent volatile solids, to 1,875 p.p.m., with 80.3 per cent volatile solids. *Sphaerotilus* was completely replaced by zoogleal colonies; the sludge regained its original color, settleability, and characteristic flora, and the bound water was reduced to 58 per cent of the volatile solids.

Discussion

The foregoing experiments have established a relationship between biochemical reactions in the activated sludge process and the physical properties of the sludge. The biochemical reactions are influenced profoundly by the type of food and the loading factor. It has been shown that the responses obtained from feeding the soluble-colloidal fraction of sewage are entirely different than those obtained from the settleable fraction. In fact, the sludge produced from feeding the settleable fraction only, cannot be considered as activated sludge but rather as some kind of aerated solids with none of the visible and essential properties of activated sludge. It is black, non-flocculent, amorphous, and non-zoogleal and it does not bulk under high loading conditions. This is a sludge formed by the adsorption and flocculation of the suspended matter which thereupon undergoes a low rate of oxidation dictated by the rate at which the solids become hydrolyzed and made available for bacterial oxidation and assimilation.

TABLE XI.—Particle Size Effect on B.O.D. Rate

	Particle Size	Per Cent of 5-Day Raw Sewage B.O.D.	k_1
Raw sewage solids	—	—	0.22
Settleable	>100 μ	15	0.08
Supracolloidal	100–1 μ	25	0.09
Colloidal	1 μ–1 $\mu\mu$	15	0.22
Soluble	—	40	0.39

Particle Size Effect

Sludge accumulates, although primarily by virtue of adsorption of particulate matter. Subsequent biological oxidation and formation of protoplasmic growth plays only a minor role. It has been demonstrated by Balmat (1) that the rate of biochemical oxidation of the various fractions of sewage is affected by the particle size as shown in Table XI.

While it is true that if primary sedimentation tanks are eliminated the settleable solids will be incorporated in the activated sludge and will affect its physical properties, the settleable solids do not constitute the essential ingredient of activated sludge. The incorporation of settleable solids in the activated sludge would tend to improve its settleability and would not add a great deal to the oxygen demand exerted in the aeration tank. By contrast, the soluble-colloidal matter can become a part of the activated sludge only as a result of biochemical oxidation, assimilation and synthesis.

It follows that suspended solids of sewage have little, if any, significance *per se* in relation to loading. Loading should be expressed on a B.O.D. basis. This applies equally well to the expression of sludge age on the basis of suspended solids in the incoming sewage.

Food Supply

These important qualitative differences (in respect to particle size) in the food in turn affect the characteristics of the activated sludge in the same manner that they affect the quantitative rates of biochemical reactions. With an abundant readily available supply of food, the rate of biological reactions is greatly stimulated; the organisms multiply rapidly, are kept in the logarithmic stage of growth and produce large quantities of sludge. In fact, the greater the load the greater the percentage of the food supply recovered as sludge and the smaller percentage destroyed by oxidation. When the supply of food exceeds the capacity of the organisms to utilize it in a given time, the excess is spilled over into the effluent.

The tendency noted with the sludge loading factor of one (sludge age of 1); namely a decreasing sludge volume index and decreasing purification, reaches the ultimate end point in modified aeration with a sludge loading factor of 3.33 (sludge age of 0.3), which manifests no problem in sludge bulking, but on the contrary produces a very dense sludge. In this case, biochemical activities are kept in check by reducing the aeration time, so that even with a disproportionate food-to-organism ratio, oxidation and assimilation with all its concomitant deleterious effects on physical sludge characteristics are eliminated.

On the other extreme, when the food supply is either greatly reduced or completely cut-off, the organisms undergo endogenous respiration whereby first the excess stored food is attacked and then the oxidation of the protoplasm itself follows; this results in steadily decreasing numbers of organisms and decreasing amounts of sludge.

It has been demonstrated that both the bulking and the bound water content of the activated sludge is somehow related to this total biological mobilization and response to the quality and quantity of the food. They are the physical manifestations and the symptoms of an excessive supply of available food in relation to the number of organisms. The evidence as to the existence of such a relationship is quite definite from the standpoint of a positive relationship of the physical characteristics of the sludge with an increasing food-to-organism ratio. The counterpart relationship exists with a decreasing sludge volume index and bound water upon reaeration of sludge without the external addition of food (sludge loading factor of zero).

Speculation exists, however, when the basic nature of this relationship is considered. What is the basic cause of sludge bulking and increase of bound water when the food and organisms relationship is wide? One possible explanation may be that the organisms produce products under these conditions which have a great affinity for water. It might be postulated that microorganisms in the activated sludge, during an active logarithmic stage of growth in the presence of abundant and readily available food, produce more capsular material of polysaccharide nature which is highly hydrated. Food is assimilated more rapidly than can be oxidized and is transformed into metabolic products, part of which is secreted out of the cell and surrounds it, forming the capsular material and the zoogleal matrix of the sludge. Although this may be a contributing factor, it is not believed capable of explaining the entire phenomenon as the following calculations will show:

Factor	Non-Bulky Sludge	Bulky Sludge
Sludge volume after 0.5 hr. settling (ml./l.)	100	500
Sludge solids (mg./l.)	1,000	1,000
Sludge index	100	500
Bound water (% of dry matter)	50	400
Volume occupied by sludge and bound water (ml.)	1+0.5=1.5	1+4=5

Sludge Volume

The values assumed for the bound water of bulky and non-bulky sludges are in accord with the experimental results. Despite, however, an assumed eight-fold higher bound water content in the bulky sludge than the good settling sludge, the volume occupied by the sludge and bound water is only a small percentage of the volume occupied by the sludge after a one-half hour settling period. In other words, the increase in the bound water content does not *per se* account for the increased volume of the sludge. Other changes in addition to the bound water, must contribute to the high sludge volume.

The following possibilities suggest themselves:

1. Water that is not necessarily actually bound might also increase. There is no distinct delineation between free and bound water, but rather a gradual transition from free to bound water with different degrees of affinities between the water and colloidal system. Some of this affinity may be due to interstitial or capillary water without being bound in the strict sense of the term. According to this concept, the increase in bound water represents only one phase of the entire change in the total water-colloid relationship of the activated sludge floc.

2. An increase in the bound water content of the sludge produces a perceptible change in the specific gravity of the sludge. The specific gravity of bacterial cells has been reported to be around approximately one (8). A sludge of a volume index of 50 and a bound water content of 100 per cent would have an estimated specific gravity of 1.05. The specific gravity of the sludge would decrease to 1.02 when the sludge bulks and contains 400 per cent bound water. Although the change in specific gravity is small, the relative weight of the sludge particle in water is reduced from 0.05 to 0.02 units, a 250 per cent reduction. The lowering of the specific gravity would increase the resistance of the sludge to settling and reduce the tendency to compact by squeezing out the loosely associated, non-bound interstitial water.

3. The tendency of the bulky sludge floc to become more irregular shaped would also tend to increase the frictional resistance to settling and occlusion of additional non-bound water.

Zoogleal Versus Sphaerotilus

Whether or not the changes in the physical characteristics of the sludge are due to one or all of these factors, or to some other factors not taken into consideration, it is clear that they are all associated with basic biochemical processes originating from the food-to-organism relationship. The change in the physical characteristics of the sludge is not the result of change in the type of organism. The physical changes were not accompanied by a replacement of the zoogleal type of growth with *Sphaerotilus*. When the sludge was induced to bulk by feeding a high ratio of soluble-colloidal material in relation to the sludge, a shift in population from zoogleal to Sphaerotilus type did not take place. The predominant organisms were still the zoogleal type but were modified in appearance. The changes were, therefore, due to a change in the biochemistry and not in the biology of the process. Similarly when a bulky sludge was changed to a good settling sludge, a change in the type of population did not take place; it was only a change in the physical character of the existing population which seemed to take place.

However, when the biology of the activated sludge was changed from zoogleal type to Sphaerotilus type of growth by feeding sugar to the sludge, and thereby inducing bulking, there was no accompanying increase in the bound water. Here other factors besides the bound water, such as the

buoyancy and frictional resistance of the filaments, will have to be invoked as being responsible for the bulking.

There was no evidence that dissolved oxygen played a role in these changes in the physical characteristics of the sludge brought about by changes in biochemical reactions. Dissolved oxygen was present in the mixture when the sludge was induced to bulk with high feeding ratios of available food to sludge.

If an attempt were made to combat bulking in the presence of large quantities of available food by increasing the concentration of the suspended solids in the mixed liquor, *e.g.* deliberately keeping the loading factors low by increasing the mixed liquor suspended solids, there is a possibility that unless the oxygenation capacity could also be increased an oxygen deficiency could set in which would vitiate the purification values. Oxygen deficiency, in addition to reducing the purification, may also affect the biology of the process by inducing the growth of *Sphaerotilus*. Thus oxygen deficiency also may be a factor in bulking. As discussed previously, there was no oxygen deficiency and no growth of *Sphaerotilus* (except when sugar was fed deliberately to induce its growth). It should be stated further that when the bulking became pronounced the experiment had to be terminated because of the operating difficulties. As a result, it is not known whether a change in biology (growth of *Sphaerotilus*) would have occurred with continued operation even in the presence of dissolved oxygen.

The results support the generally held view that there are two types of bulking: Sphaerotilus and zoogleal. According to the experiments Sphaerotilus growth occurred only when sugar was the substrate. The feeding of soluble material in sewage did not induce the growth of *Sphaerotilus*.

Possibly had the experiments continued longer or an oxygen deficiency existed, *Sphaerotilus* might have developed when soluble-colloidal material of sewage was fed at high loadings. There is another difference in the characteristics of the two types of bulking, however: one type is accompanied by a high bound water content while panied by a high bound water content, the other is not. Present knowledge reveals that there is justification in recognizing the different types of bulking, but it is not clear why a high energy food such as sugar should induce Sphaerotilus growth and the soluble-colloidal fraction of sewage should not.

Chlorination

The use of chlorine to control activated sludge bulking deserves some discussion in this general tentative concept of bulking. The action of chlorine appears to be a physical one since the addition of chlorine has an immediate effect in reducing the sludge volume index and the bound water. The previously held views that chlorine acts beneficially by keeping in check the excessive biological activity or by selective killing do not seem to be tenable. The effect can be explained most readily by stating that chlorine releases the bound water from the floc. It would be necessary to assume, however, that the water is associated with proteins which become denatured by chlorine and, thereby, lose their water. It is doubtful whether chlorine could effect the water held by the polysaccharides.

Effect of Loading

The tendency for the sludge volume index and bound water content to decrease, which was noticed with a sludge loading factor of one, might be expected to continue with increasing loadings until a loading factor of 3.3 is reached. At this point the sludge volume index is very low and the

bound water content is also low. This is illustrated by the values obtained from a sample of modified aeration sludge:

Sludge volume index = 29.
Bound water per cent of volatile solids = 68.

In addition to not having the physical properties of activated sludge, modified sewage aeration sludge does not give the same degree of purification as obtained by activated sludge. Despite the high sludge loading factor in this process, biological activity and assimilation is kept at a minimum by reducing the contact time. It appears that the so called high-rate activated sludge processes being developed, particularly for the treatment of industrial wastes, are somewhat analogous to the modified sewage aeration process. That is, under these high loading factors the percentage purification is lower than with conventional activated sludge, and the sludge being overpowered is not flocculent and does not bulk or have a high bound water content. In fact these high-rate processes cannot be considered as activated sludge processes. All they have in common is that they are all aerobic, biological processes. In order to avoid confusion, it would be best not to refer to them as activated sludge processes but instead as aeration or bio-oxidation processes.

Conclusions

1. The bound water content of a zoogleal type of bulky activated sludge is higher than that of a sludge with a low sludge volume index.

2. The continuous aeration of a bulky zoogleal type sludge, without feeding, resulted in a decrease of both the sludge volume index and the bound water simultaneously with a decrease in the sludge-oxygen demand.

3. Cessation of chlorination of the return sludge in an activated sludge sewage treatment plant resulted in an increase in the sludge volume index and bound water.

4. Chlorination of a zoogleal type bulky sludge gave an immediate decrease in sludge volume index and bound water.

5. Feeding of activated sludge with the soluble-colloidal fraction of sewage at a sludge loading factor of 0.5 resulted in an increase in sludge volume index, bound water, sludge oxygen demand, and percentage of the B.O.D. fed recovered as sludge and in the nitrogen content of the sludge. Feeding the same fraction at a loading factor of 0.3 did not give in increase in sludge volume index, bound water, and sludge oxygen demand, and gave the smallest percentage yield of sludge in relation to the B.O.D. fed. A sludge loading factor of one gave a lower increase in sludge volume index, bound water, sludge oxygen demand, and percentage of the B.O.D. fed recovered as sludge than sludge fed with the same fraction at a loading factor of 0.5.

6. Feeding activated sludge with the settleable fraction of sewage did not give any increase in sludge volume index and bound water even at the highest loadings employed. Sludge did accumulate, but this was not due primarily to microbial assimilation and synthesis, as indicated by the failure of the nitrogen content of the sludge to increase. It was due primarily to adsorption of the settleable solids fed by the activated sludge.

7. To obtain a Sphaerotilus type of bulking it was necessary to feed sugar. On bulking this sludge did not give an increase in bound water.

8. The increase in bound water and the increase in the sludge volume index are considered to be associated phenomena. They are the result of biochemical processes induced by excessive supply of available food in

relation to the number of organisms (amount of sludge in aeration tank).

9. The results of this study do not indicate that the dissolved oxygen or nitrate content of the aeration tank are responsible for or are symptomatic of bulking.

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THIRSTY

Thirsty citizens and industries have caused one out of four of the larger urban areas to report that they will need additional water supplies to meet continued municipal and industrial growth. This information was reported recently by the U. S. Public Health Service in announcing results of a nationwide inventory of 1,532 community water facilities.

The inventory covered all facilities serving 10,000 people or more and a 40 per cent sample of those serving between 5,000 and 10,000. The survey was carried out under a directive from the Office of Defense Mobilization as part of the Government's mobilization readiness planning activities. It lists, among other things, population served, source of supply, treatment provided, capacity, storage and the improvements which local officials consider necessary to main satisfactory service.

More than one-half of the water supply facilities covered by the survey were reported as needing improvement or enlargement, but not all of these involve development of new sources of supply. About one-fourth of the facilities need additional distribution systems, due in part to the growing practice of municipalities to provide water service to suburban areas.

Greater conservation of available water resources through pollution control is becoming more apparent in many areas. The adequate treatment of wastes to permit more extensive use of available surface water is the logical answer to some of the present supply problems. The situation provides a provocative challenge to the sanitary engineer.

THE OPERATOR'S CORNER

CONDUCTED BY DONALD P. SCHIESSWOHL

1955 OPERATORS' FORUM *

ARTHUR H. NILES, *Leader*

Commissioner of Sewage Disposal, Toledo, Ohio

Chairman Niles:—Our plan is to divide this discussion into about three parts. The first part is to be for the larger sewage treatment plants with problems of organization. The second and third parts will be devoted to the problems of middle-size and small plants.

Organization of Large Sewage Treatment Plants

George S. Long, Operations Supervisor, Sewage Treatment Works, Akron, Ohio:—The topic I wish to discuss is vertical versus horizontal supervision at sewage treatment works. Vertical supervision is shift supervision, limited in time but unlimited in space within the plant area. It might also be called operation supervision. In horizontal supervision, space is limited but not time. In other words, it is department or product supervision.

This is not a subject of great interest to small plant operators or to operators of large plants where only partial treatment is practiced. The problems of a screening plant, for instance, can be handled by the plant superintendent with shift foremen to care for the operating detail. The problems of a large treatment plant having complete treatment and sludge disposal, however, are often more than one man can cope with successfully. Then, it becomes necessary for the superintendent to have technical assistance in some form. Product supervisors or department supervisors may be employed to handle the details of the various operations (horizontal supervision). Alternatively, if the superintendent is able and chooses to handle all the detail himself, he may need only chief operators or shift supervisors to oversee the operations on each shift (vertical supervision).

With vertical supervision the shift supervisor is, for all practical purposes, a shift foreman directing the work of the operators and others on the shift. He plans the work of the shift only in aspects that deviate from the routine. He sees to it that the operations in process at the start of the shift are carried on, perhaps makes some slight modifications, and he turns the plant over to his relief practically as he received it. He may think that a certain operation should be modified, but he does nothing about it because the superintendent has not ordered it, because his relief may not agree with him and because he has no authority to issue orders affecting other shifts. If he is on a night shift he may not see the superintendent for several days and then it may be too late to discuss the change. He may

* From transcript, 28th Annual Meeting, Federation of Sewage and Industrial Wastes Assns.; Atlantic City, N. J.; Oct. 10–13, 1955.

think that the superintendent is familiar with the condition and wants it to exist. He will do what is needed to keep the plant operating but he will not change operations and thus improve production.

With horizontal supervision, each supervisor is a department or division head with a chief operator or shift foreman to handle the operation details during each shift. For example, there might be a supervisor of primary treatment, a supervisor of secondary treatment and a supervisor of sludge disposal. In some treatment plants it might be possible to combine two of these departments under a single supervisor. In extremely large plants it might be necessary to subdivide some of these departments. In all cases, however, each department head would be responsible for the operation of his own department and, by studying the effect of various changes in operating procedure, could maintain a high level of efficiency.

Plant maintenance and laboratory control are one-shift jobs which are best handled by general supervision, directed by the superintendent through a maintenance supervisor and a chief chemist. Personnel is another area suitable for general supervision under a personnel supervisor responsible for handling the various grievances and other related matters with which the superintendent is constantly besieged.

These conclusions have been drawn from experience gained at the Akron Sewage Treatment Works during the past 12 years. The plant was constructed in 1928 to handle 33 m.g.d. through Imhoff tanks and trickling filters, with the sludge dried on open beds. This type plant did not present many problems in supervision and none in shift supervision. Only two men per shift were required to handle night operation.

However, the original treatment plant was overloaded within two years after completion. Sludge drying capacity was grossly inadequate and kept supervision constantly on the jump to provide additional sludge bed area. With the manpower shortage that developed with the advent of the Second World War, it was impossible to get labor to clean the sludge beds. Therefore, lagoons were constructed until there were 45 acres of lagoon area with a capacity well over 1,000,000 cu. yd.

New sludge digestion and disposal facilities were started in 1948 and completed early in 1953. This relieved the lagoon situation but did not improve the overloaded condition of the Imhoff tanks and trickling filters.

Construction currently in progress on a new detritus unit, primary settling tank and activated sludge facilities will provide ample capacity for present needs. When this treatment plant is put in operation, it will require an operating force of from 15 to 20 men per shift. In addition, there will be a maintenance force of 25 or 30 men, and an administrative and laboratory force of at least 7, making a total of about 100 employees.

The efficient operation of the new plant will depend to a large extent on the organization of this group into a smoothly working force. The question is: should it be organized with vertical or horizontal supervision?

Chairman Niles:—We will continue this discussion by hearing two operators from large sewage treatment plants, one from the Chicago Sanitary District and the other from New York City.

A. H. Goodman, Sanitary District of Chicago, Chicago, Ill.:—As mentioned by Mr. Long, the size and type of treatment plant determines to a great degree the organizational pattern most desirable for the supervisory staff. In a plant where there are 20 or more men on duty per shift, I believe that the vertical or shift supervision plan is essential. These shift supervisors should be thoroughly ac-

quainted with the operation of the various treatment units and act as leaders in responsible charge of all routine and emergency operations on their shifts. Without adequate shift supervision, the best plans made by any horizontal supervisory setup will be greatly handicapped.

I believe that, in a treatment plant of the size mentioned, there cannot be a clear-cut choice of vertical or horizontal supervision but rather a combination of both. Sometimes it will even be necessary to follow a diagonal path. It is, of course, highly desirable to establish the best possible theoretical organization for supervision of a treatment plant. However, I believe that most operators are faced with the problem of having employees with certain abilities and limitations and are forced to fit the organization to the available personnel.

Arthur J. Scanlon, Chief of Maintenance and Operation, Bureau of Sewage Disposal Operations, Department of Public Works, New York City, N. Y.:—About 20 years ago we put in a sewage treatment plant of about 20 m.g.d. at Coney Island. At the present time the New York City Department of Public Works operates and maintains 15 sewage treatment plants treating over 600 m.g.d. In 1952, three new sewage treatment plants were placed in operation having a design capacity of around 300 m.g.d. Prior to the opening of these three new plants organizational problems were anticipated and were gradually settled on the basis of a horizontal supervision on a high level.

In treatment plants there is definitely vertical supervision of the operating personnel from the chief operator down. However, with so many plants, horizontal supervision has been the best solution to some of the problems.

For instance, we have four self-propelled sludge vessels servicing 9 plants. Every so often the sailing schedules are delayed because of fog or storms and then there are usually 9 chief operators on the telephone asking "When do I get a boat?" You cannot give them all a boat immediately so we have a port captain in the bureau office who is responsible for proper scheduling and operation of the sludge vessels.

Another problem is that the operators cannot find time to do all the repairs and the necessary maintenance. Routine operation work eventually suffers if they try to do too much. As a result, some of this work must be done by outside agencies or contractors. This requires another horizontal setup which consists of staff men to write specifications and provide inspection for mechanical and structural contract work. There are also staff men who provide the above services for all the electrical equipment.

Treatment problems are another phase of sewage operation which are most suitable to horizontal supervision. The staff men in this section look at the whole setup for all 15 plants and make plans accordingly. For instance, sometimes one treatment plant will work out a new solution to a problem. Then the treatment men, working along the lines of horizontal supervision, can instruct and carry out the procedure at other plants.

We have 35 gas engines in eight of the plants and repairing them under contracts has been troublesome. When you have to write a contract for repairs to an engine without knowing exactly what is wrong with it, you are looking for trouble. You generally get it because there are always extras for repairs that are required when the engine is dismantled. As a result of this problem, a gas engine maintenance force has been formed and carries out the repair work required. This force has been completely satisfactory and is an example of how horizontal control can be effective.

Vertical controls of the operating shifts at the different plants and horizontal controls at a higher level have proven satisfactory. The blending of both vertical and horizontal controls into a coordinated unit results in smooth operation. As Mr. Goodman put it, diagonal control accomplishes the same thing.

Ralph A. Hoot, Chief, Sewage Treatment Section, Philadelphia, Pa.:—Philadelphia has three sewage treatment plants, two of which have been completed and a third one will be in operation in December, 1955. These three plants will have slightly more than 200 employees. At the Northeast works there will be 10 men on each shift; at the Southwest works, 6 men; and at the Southeast works, 5. This makes a total of 21 operating employees per shift.

When I started work in Philadelphia five years ago, I had hoped to hire four young graduate engineers or chemists, who would be stationed at the Northeast works in the laboratory and would be the key men. They would be the shift supervisors in addition to being responsible for the laboratory work. Unfortunately, we were unable to obtain the desired type of person at the time.

At the present time, in the Northeast treatment plant we do have what we call "round-the-clock" laboratory control. We have four chemists covering three shifts. Not all have college degrees, but they are good operators who came from the water department and whom we have trained to do laboratory work.

Experience has taught us that 10 men on a shift were sufficient for dry weather flow when there were no troubles, but they were inadequate for other conditions. We were plagued incessantly by men failing to report for work. Quite frequently we had trouble with sludge pumping and during storm periods, there was quite a lot of difficulty with the old machinery. So through the months, it gradually developed that one extra man was placed on each shift. He is simply an extra sewage treatment operator. These men happen to be men who have been employed the longest and they are sort of working into the pattern of a shift supervisor.

At the Southwest works, where there are six operators, it looks as if the pumping operator will gradually develop into a key man, primarily because his headquarters will be in a building where the laboratory and offices are located and he will have convenient access to a telephone. At the present time, however, the pumping station operator will stay at the same level as the sewage treatment operators in that treatment plant. Eventually someone on each shift in each plant will become a sort of key man.

I agree thoroughly that there is no vertical and horizontal supervision that will work perfectly in any treatment plant.

We are gradually enlarging the staff in Philadelphia and getting somewhere. Our new Civil Service Commission is splendid and, even though some of the things I have in mind are not coming as rapidly as I would like, working conditions are vastly improved from what they were in 1950. For instance, several of the staff have had professional training. I am a civil engineer with a sanitary option. We also have a chemist and a chemical engineer. An electrical engineer, who will be on the staff level, has just recently arrived. Although the electrical and maintenance men will still be in charge of the maintenance work of the three plants, it is hoped that the new engineer will have considerable to do with the electrical layouts in the plant and will advise us. He will also probably be the key man for the time being at the new Southwest works. Next year we will have an opening for a mechanical engineer

who will be on the staff level and will also be the key man on maintenance work.

Chairman Niles:—Problems of the middle-size and small sewage treatment plants are of concern to many of the operators. The next discusser is from a middle-size plant in upstate New York.

Digester Scum Control

Uhl T. Mann, Superintendent, Sewage Treatment Plant, Onondaga Public Works Commission, Baldwinville, N. Y.:—Probably the greatest single difficulty experienced with the operation of our sludge digestion units has been scum. Most digester scum is composed of an accumulation of grease, raw and digested sludge, plus such materials as matches, hair, paper, rags and many inert materials with a low specific gravity. These scum-forming materials come from industrial plants such as: slaughter houses, meat packing plants, food processing plants, soap factories, oil refineries, tanneries, machine shops and hat and glove factories.

The scum to which I have reference is the type that reaches a depth of 4 to 8 ft. and acquires a consistency which makes it impossible to be moved by pumps. This condition is not universal, but many instances of serious scum problems have been reported in the literature. Some of these have been corrected; others remain a perplexing problem.

The presence of a heavy layer of scum at the top level of the digester presents the following problems:

1. Loss of digester capacity.
2. Increased cost of operation.
3. Danger of damage to the digester structure in the event scum prevents normal overflow of supernatant or sludge.

Practically all digester scum problems are the result of adding screenings and grease from primary clarifiers. It is well known that grease digests quite readily at a temperature of about 95° F., if conditions are such that intimate contact of bacteria and other microorganisms can be made with the particles of grease. To provide the needed contact, some form of mixing must be used. The literature refers to both gentle and violent mixing. The gentle mixing is usually accomplished by recirculation of warm supernatant liquors into the gas dome or by slow moving mechanical scum breakers. The more violent type of mixing is provided by high capacity mechanical mixers or by gas dispersion devices. In most instances one or the other type of mixing has eventually proved successful in scum control. There are, however, instances where both methods have failed to improve conditions.

Studies conducted at the Ley Creek sewage treatment plant in Syracuse (N. Y.) some years ago showed that grease digested quite readily at 95° F., but that a mixture of grease and ground screenings required almost twice as long a digestion period. It was also shown that materials like pieces of rags, hair, straw and small pieces of wood never digested in a normal digestion cycle and eventually had to be removed from the digesters. Another item that adds to scum troubles is the increasing use of industrial paper towels. This type of paper requires a considerably longer digestion period than do toilet and facial tissues.

The studies at the Ley Creek plant also showed that the digestion of sludge with grease and screenings required a longer period than for sludge alone. It was also demonstrated that the volume of gas produced with grease and screenings was greater than the volume produced from only grease. However, the volume of gas produced per pound of volatile matter was lower than the gas from sludge alone. The most pertinent fact brought out by the

Ley Creek studies was the loss of capacity due to a gradual build up of a layer of scum which reduced the active capacity of the digester. Continuous mixing improved the scum conditions but never reduced the layer sufficiently to restore the digester to normal active capacity. Another test run, with digestion of sludge only, failed to develop any noticeable scum conditions. As a result of these studies, the pumping of grease, scum and screenings to the digesters was discontinued, and since then no scum troubles have been experienced.

According to Rudolfs (see *Sewage Works Journal*, **16**, 6, 1125 [Nov., 1944]) the addition of too large a quantity of grease to a digester may result in a rapid accumulation of fatty acids which will lower pH values. Acid conditions retard methane producing organisms but do not affect carbon dioxide production. If the greases contain an unusually large amount of soaps, it is necessary to supply additional nitrogen to promote proper biological activity. The presence of large quantities of certain types of mineral oil will inhibit the processes.

There are two methods for solving the problem of scum. The best method is to exclude the bothersome materials at the source. This is the simplest and most effective method but it is not always practical or possible. The other method is to provide control methods at the sewage treatment plant.

The Ley Creek treatment plant experienced difficulty for a 9-year period during which ground screenings and scum were pumped to the digesters. In two years the scum would accumulate to a depth of about 4 ft., necessitating dewatering of the tanks to remove the accumulated scum and thus restore capacity needed for normal operation. On one occasion 30 days of continuous recirculation of sludge from the zone of active digestion to the gas dome failed to improve conditions. This condition was probably caused by the presence of hair and paunch manure which matted the top scum together in a mass that would not move to the gas dome to be broken up.

During a construction program in 1950 an incinerator was installed for burning screenings and skimmings. The specifications called for sufficient capacity to incinerate to complete combustion sewage screenings of approximately 90 per cent moisture content at the rate of 1,000 lb. per hour. The incinerator was equipped with dual-fuel burners to burn gas, oil or any combination of these fuels.

The present operating program calls for preheating with gas, use of oil with gas to facilitate burning, and then the use of gas alone to complete the burning cycle. The unit is normally operated every other day and is used more often if needed.

If the present Ley Creek digester capacity of 240,000 cu. ft. were operated with the same scum problems encountered at the treatment plant 10 years ago there would be an annual loss of 18,000 cu. ft. of digester capacity, with the resulting need for cleaning every two years. The loss of capacity would have a value of $50,000.

The scum problem at this plant has been eliminated by the investment of $14,000 for an incinerator. We agree that there are several methods for improving or controlling scum conditions, but we also feel that any material which might tend to cause scum should be removed from the sewage and not pumped to the digesters. Even though these materials have value for the production of gas, the value of the gas produced will be relatively small compared to the capital investment required to provide additional capacity.

John O. Barrett, Superintendent, Westerly Sewage Treatment Plant, Cleveland, Ohio:—It has been stated that one treatment plant has a scum

problem because it has 4 ft. of scum accumulation in a year. If I had only 4 ft. of scum accumulation in a year I would think my problem was solved. It happens that on the average, we accumulate about 1 ft. per month in each digester. It is imperative to pump down the digesters annually. This year the scum has been removed from each digester once and some will be cleaned a second time. I don't know exactly what the present accumulation rate is because, in going over my data for the September, 1955 report, I found that an average of almost 3 ft. of scum had accumulated in each digester during that month. This means all of the solids rise to the top, but I have no means of removing solids from the top of the digesters. The scum must be broken up and pumped from the bottom.

However, we have been experimenting for more than a year with gas recirculation. Some features of gas recirculation have proven successful, but it hasn't solved our problem. We are using this system in an old digester installation with only two points of application. This limits the effectiveness. One thing we did find was that, as Mr. Mann has said, there are certain kinds of material in the scum which do not digest at any time. We have our percentage of that type of material. We are also adding all our grease to the digesters. The Imhoff tank gas vent scum is not added to the digesters but mixed with digested sludge and filtered. Scum is an ever-increasing problem at our plant and I don't see any solution to it in the near future.

We know that if certain things are kept out of the digester we would have fewer problems. We are attempting, in the industrial wastes program, to educate the packers not to put in various materials. They inform us that they sell all of their wastes such as hair and grease as by-products and don't put them in the sewers. A large number of industries are involved, however, and we realize that, by the time each one adds a small amount of the materials they say they don't, the accumulated total over the period of a year can give the treatment plant a great problem.

We could possibly separate the grease, but we also get straw, hair, entrails and hoofs, as well as paper and rags. I have never seen a method whereby these could be separated. Probably fine screening would do the job, but that would take us back where we started years ago. There still are a lot of questions to which we have not found answers. We go along a couple of steps and think we are on the right track and then something else comes along and gives us another shock.

William H. Higgins, Superintendent, Sewage Treatment Works, Ewing-Lawrence Sewerage Authority, Trenton, N. J.:—We have been in operation about two years and we pump about 2,000 cu. ft. of raw sludge every day. About six months ago we found we had about eight feet of scum in the digester. We finally added 20 lb. of alum to the raw sludge and reduced the scum depth from 8 ft. to 2 ft. That seems to be the answer to our scum problem. Of course, we had to add lime to keep up the pH in the digester. That was our way of solving a very acute problem. The scum also clogged the supernatant selector screens in the digester and the alum also cleared them up.

From the Floor:—I would like to ask Mr. Higgins what he is going to do with the stuff at the bottom of the digester after he has used alum for some time.

Mr. Higgins:—We realized when we started adding alum that we might have trouble with the thick sludge in the bottom of the digester, so about every two days we draw sludge and so far we haven't had any trouble. Of course, we have only been experimenting with it for about six months.

Chairman Niles:—What about your gas production and volatile acids?

Mr. Higgins:—The gas production went from about 350,000 cu. ft. per month to close to 1,000,000 cu. ft. I don't recall the volatile acid values.

T. R. Haseltine, Chester Engineers, Pittsburgh, Pa.:—I am no longer an operator, but I am very much interested in the operator's problems. I was particularly interested in Mr. Mann's statement that these scum-forming materials had no business in a digester. I think that would indicate that he does not favor comminutors or screen shredders. I think I agree. But what about this matter of grease? Maybe it doesn't belong in a digester, but what are you going to do with it?

Some years ago we had an incinerator in the Erie (N. Y.) sewage treatment plant and we attempted to burn the grease. But at times there was so much grease we almost burned up the plant along with the grease. It is a terrible job to try to run an incinerator on the skimmings because they are so variable in their heat value. You can't control the incinerators or the loading.

Darwin B. Kissinger, Superintendent, East Side Sewage Disposal Plant, Topeka, Kans.:—Our scum is taken care of by mixing and steam injection. We take feathers, hair and anything that we can handle cheaper than industry. In fact, a lot of things are received that can't be satisfactorily handled. We have about 75 per cent volatile sludge coming out of the digester and 50 per cent solids. We are very pleased with our digester operation.

C. C. Larson, Chemist, Springfield Sanitary District, Springfield, Ill.:—I think one of the most gratifying and comforting things about coming to one of these forums is to find that you are not as badly off as some of your compatriots.

When I left Springfield last week we were in the throes of emptying a 95-ft. digester. It is a messy job and we feel terribly abused to have to go into it once every five or six years. At this forum I find men talking about cleaning their digesters every year or two, so I guess perhaps we don't have any justification for feeling sorry for ourselves. It is just a matter of routine apparently.

On this subject of scum, the tank that we just cleaned was stuck completely. The gas production had fallen off to virtually nothing. There was about 3 ft. of scum which was dry enough to walk on and also a great amount of mineral oil. Unfortunately the oil doesn't stay on top. It mixes with the hair and the rough material so that it is found throughout the entire scum layer. I think we all agree that mineral oil has no business in a digester, but it is pretty hard to keep it out unless you burn the material that you take off your skimming basins.

I have heard glowing reports about recirculation with gas. If it will accomplish one-half of what is claimed for it, it should be the answer in regard to this scum problem. I have always maintained that a healthy digester will always have a certain amount of scum in an active state of digestion.

My concept of digestion is that the sludge comes into the digester a little chilly. It begins to warm up and, of course, goes to the top and there the digestion or fermentation takes place. After the buoyant organic matter has been reduced the sludge gets heavy enough to settle to the bottom of the digester. So, while there is always a layer of scum at the top of the digester, it is a continually changing layer and I believe that the bulk of the gas is produced in this scum layer. But when it gets dry enough to walk on, that is a different matter.

We have not gone in for stirring with gas yet but we are considering it very seriously. Frankly, I think it

has much more promise than control with chemicals. We have discussed the question of whether or not to add lime to the digester for 20 years and it was with a certain degree of disappointment that I heard Mr. Higgins report that they were not only liming but were also adding alum to a digester. Recirculating gas at least does not put any foreign matter back into the digester. This is an important matter and I should like to hear more discussion on it.

Chairman Niles:—Just to make some of you operators who don't have to clean digesters more than once every four or five years feel good, I might say that in Toledo we have 8 digesters. Four of them have never been opened; have never been cleaned in 23 years of operation. Of the other four, three have been cleaned once and one of them twice.

J. B. Hanlon, Superintendent, Sewage Treatment Plant, Metropolitan District Commission, Quincy, Mass.:—I like Mr. Mann's method of destroying undigestible scum material by incineration. We have been thinking about using this method: that is to pump this material at a controlled rate, say 3,000 to 4,000 gal. per week, from each primary digester to an incinerator and burn it, together with other combustible materials accumulated around the plant. This would solve both the problem of scum accumulation and that of disposal. We collect about 400 tons of grease and scum per month, 100 tons of which is non-saponifiable.

This material developed a scum layer 12 to 14 ft. in depth in the secondary digesters. We were aware of this build-up taking place, but postponed tank cleaning while trying other less drastic means of solving the problem. Early in 1955 it was necessary to move the floating cover. This caused the scum blanket to tip, which forced the vertical piping out of alignment with the gas dome and inspection manhole inlets, damaging some pipes and splitting the gas line.

The cleaning of this digester did not present any great problems. Good ventilation was obtained by borrowing the main building ventilating fans and connecting them to the digester manholes. Nobody enjoyed the work, but it wasn't any great project. The job of cleaning the second digester is now well along. We used about two tons of sodium hexametaphosphate (Calgon) as an experiment to liquefy heavy, fibrous scum and it certainly did help.

Walter A. Sperry, Superintendent, Aurora Sanitary District, Aurora, Ill.:—I just wanted to ask Mr. Hanlon to expand on the use of Calgon.

Mr. Hanlon:—I am not a chemist. In the literature on new products I read about the use of Calgon. Somebody brought me a pint bottle of Calgon which I tried in one of the grease pits and was pleased with the effect it had on the collection of skimmings and grease. The Calgon would liquefy the grease and scum, making pumping possible. We used larger quantities than necessary in the first digester cleaning job and I was convinced later that we did not get good mixing. The scum blanket I am talking about resisted shoveling, that is, the material that was really dry.

In the first cleaning job we poured the Calgon solution into the digester through the top openings, and used hoses for mixing and moving accumulations of the scum material which remained on the pipes. Later we used a large sump pump to introduce the Calgon into the digester. Better mixing was the answer to improved liquefaction of the scum.

John W. Hood, Superintendent, Sewage Treatment Plant, Ridgewood, N. J.:—Some years ago Colonel Hardenbergh and I compared notes and decided that we could do some research work and find out why some areas suffered from scum and some did not.

We found that where the water supply had a high salinity there were no scum problems, but the treatment plants had corrosion and failure of metallic structures in the digesters. At the Ridgewood sewage treatment plant this information was translated into terms of sewage treatment plant practice some 17 or 18 years ago as a result of finding out that we too were developing a scum problem. We did not have a scum problem at first because of the enhanced SO_4 content in the liquid and solid constituents due to chemical precipitation with aluminum sulfate. Much of the sulfate naturally found its way into the digester with the accumulated sludge. When we discontinued aluminum sulfate coagulation, during World War II, we began to experience scum build-up.

It would seem that although carbon and nitrogen are generally recognized as nutritional elements, there are groups of organisms concerned with the assimilation and transformation of fat and grease which need sulfur for their structural and metabolic requirements. This is a strange fact but, as Mr. Higgins has reported, when you use it skillfully you can benefit by it. When you overdo it, you get into trouble.

From the Floor:—I am amazed to find from Mr. Higgins that he is using only 20 lb. of alum for 2,000 lb. of raw sludge. That is hardly more than you get from the normal use of toothpaste.

Mr. Hood:—That is correct. We were using 25 lb. of alum per day to 7,000 gal. of sludge input averaging 4 per cent solids and we had to reduce the amount used because the solids in the bottom of the digester increased to 12 per cent which we couldn't get out. So we simply controlled the amount of aluminum sulfate to get back down to about 8 per cent solids content.

From the Floor:—This discussion seems to have settled down to the scum problem entirely. How many of the operators are still bothered with pulling heavy sludge out of the digester?

Chairman Niles:—The two are very closely allied. If your solids don't sink they go to the top and you have scum.

From the Floor:—The reason I brought that up is that the engineers at the treatment plant in Chicago discovered that Calgon or sodium hexametaphosphate is an excellent material for liquefying that concrete-like substance that forms in the bottom of the digester when there is a carry-over.

I understand that Calgon is used in the oil fields to maintain the sludge in the mud to counteract the effect of the oil and gas in the boreholes. This makes it possible to pump out the stuff that ordinarily has to be dredged out with a clam shell. It has been reported that 3 lb. of Calgon was left overnight in a digester that had been de-watered almost as far as it could be. Amazingly enough, it was possible to remove about a quarter of these solids the next day by pumping. And, instead of spending weeks trying to get the stuff out the operator was able to pump it all out in three days. Calgon seems to put the solids into a suspension by a physical rather than a chemical action; it just sort of lubricates it more than anything else.

Mr. Mann:—There is no doubt that detergents help. We found that the bottom stuff moves more easily with a gradual increase in the use of detergents. They disperse the materials.

F. H. Miller, Chief Engineer, Hampton Roads Sanitation District Commission, Norfolk, Va.:—We have tried gas recirculation on three digesters. On one of them the cover was floating on 6 or 8 ft. of scum solids, with practically no contact with the liquid. Gas was blown in and circulation obtained at two points. It apparently did bring some of the scum in contact with the liquid but very little progress was made. On another active digester

the gas production increased 30 to 40 per cent for a period of about 10 to 14 days. The digester stayed active, but there still was about the same amount of scum over a large part of the digester surface area.

The third digester happened to be one on which a cover had not been installed and just air was blown in to see what the physical action would be. We broke up perhaps 20 per cent of the scum area in about 10 days time but the rest of the scum seemed to stay together and in place.

We are of the opinion that gas recirculation will blow a hole in the scum layer but that it doesn't help too much on the circulation.

Mr. Barrett:—During our first experiment with gas recirculation, a small compressor was used. Three points of application through the cover were available. The edge position was too close to the edge of the cover to be practical. The intermediate point could not be sampled but we found that at the center position an area 8 ft. in diameter was well broken up. Gas, applied by use of a pipe inserted at the periphery and moved at short intervals, proved effective.

To determine the relative operation of a digester with gas recirculation under ordinary conditions, another digester was run in parallel attempting to keep all conditions equal, such as solids added and temperatures. After a period of several months, the scum depth in the recirculated digester was about one-half that of the control digester. However, laboratory analysis showed that the solids content in the scum of the experimental digester was double that of the control. Therefore, the scum was compact, but had an equal weight of dry solids. When the digester was pumped down for the removal of the scum, the concentrated scum caused the steel members supporting internal piping to bend and the gas line to break.

The experiment was repeated using a large compressor and four intermediate points of application. This application we feel will be much more effective but the piping arrangements make the taking of samples difficult. Sampling at an inspection well near the edge of the cover indicates a slow scum build up, but this sampling point is not representative.

The consensus of opinion seems to be that gas recirculation of one type or another increases gas production. However, we have found that the recirculation of supernatant or of gas does not give us any appreciable increase in gas production. Recirculation has indicated improvement over a short period of time but results are not conclusive.

Another interesting fact is that at the present time two of our 50-ft. digesters have scum blankets of approximately 9 ft. in depth and these digesters are now very active in gas production. Therefore, it does not always follow that having heavy scum accumulations means poor gas production. I am not trying to give explanations but merely indicating our experience. Good gas production with limited digester capacity may be due to accelerated digestion or higher charging rates for available capacity. The higher production of gas results in a natural recirculation of solids which, in my opinion, is the best type of recirculation and surely the least expensive.

Chairman Niles:—Of course, any digester that is rapidly gasifying is active and there isn't anything that is dead about it, regardless of how much scum there is on the top.

W. T. Barron, Superintendent, Sewage Treatment Plant, Hampton Roads Sanitation Commission, Norfolk, Va.:—The test run on gas recirculation in an active digester increased gas production by 22 per cent. Previously 98 per cent of the gas was produced in the primary digester. After we had recirculated gas into the active

primary digester for approximately 10 days, the gas production split may be 60–40 showing that the sludge was mixing and going over into the secondary digester more than it had heretofore.

L. S. Kraus, Chemist, Greater Peoria Sanitary District, Peoria, Ill.:—We have an activated sludge treatment plant with four 85-ft. digesters operating in parallel and two open-storage tanks for secondary digestion. All of the primary digested sludge is transferred to one of the two secondary tanks so that all of the secondary scum will form in one tank. We have no scum problem in the primary digester and I think the mixture of fresh solids and activated sludge helps to prevent scum formation. Somehow, when you digest fresh solids only, I think the scum problem is greatly intensified.

We draw overflow from the primary digesters immediately under the top of the fixed-cover, so we have no scum whatsoever in these tanks. However, if the method of withdrawal were changed it wouldn't take long before there would be scum formation.

Odor Control

Chairman Niles:—Let us now consider the matter of odor control. John Hood knows the problems of the small-plant operator, and will be glad to discuss that which is so interesting regardless of plant size.

Mr. Hood:—The odor problems have been so long associated, in the public mind, with sewage treatment that today we are facing it as our No. 1 problem. It is a psychological problem and that immediately leads to point No. 2 which is the terminology associated with the problem.

Believe it or not I am surprised that we have almost 300 women registered at this Federation meeting. It is a fact that many women cannot tell Mrs. Jones or Mrs. Smith that they are going to a sewage operator's affair, because immediately they have a revulsion and there might be serious social consequences.

We would like very much to have the Federation take into consideration this very serious psychological handicap which the name "sewage" and the stigma attached to sewage treatment personnel causes, although we consider ourselves very respectable people.

Point No. 3 has to do with the origin of odors. They may occur in the following order: the sewer system, the pumping stations, the interceptors, and the treatment plant, with particular emphasis on the sludge digester. The second part about point No. 3 is the allocation of blame or responsibility for odors because people again have the almost universal tendency to put the blame directly on the sewage treatment plant. Those of us who do not operate the collection systems find that we have to reach out beyond our immediate boundaries and make some suggestions to those who do, so we can protect ourselves against having odor problems at the plant.

Point No. 4 deals with practical and technical aspects of the odor problem. They are so associated with the practice that we are forced to consider them also.

Point No. 5 is that an ounce of prevention is better than a pound of cure. Only a fundamental approach will prove economically effective in the long run. Basically the problem of odors should be attacked at the beginning, in other words, at the sewer system and not somewhere between the system and the outfall. If you have succeeded in controlling odors and have established a program, see that it is being followed.

Chairman Niles:—To approach the problem of odor control as the treatment plant operator has it, rather than from the speculative standpoint or the theoretical, what is the small-plant operator doing in the way of cleaning up these places where odors accumu-

late? I know, from experience, that any place where greases of animal or vegetable origin can accumulate and undergo a degradation process, is certain to produce odors.

From the Floor:—Mr. Hood's reference to the psychological effects of the name sewage in connection with odors prompts me to mention the name of the new sewage treatment plant at Rockland, Conn. The superintendent of the water and electric utility in that town decided that while the treatment plant was being built and also now that it has been built, that it will not be called a sewage treatment plant, but the Groton pollution abatement facility. The plant is close to houses and I think there is something in calling it a pollution abatement facility instead of a sewage treatment plant.

Chairman Niles:—I think that is a very worthwhile suggestion. Any of you operators who have trouble with some of your local people who think that taking a trip to the sewage treatment plant is something that isn't done, just spring this term on them and maybe they will come down and see what it is all about.

Mr. Larson:—A rose by any other name will smell as sweet.

C. C. Feely, Superintendent, Bergen, Field and Dumont, Dumont, N. J.:—It used to be that when you went into a sewage treatment plant everybody around the countryside knew it and when you mentioned the word "sewage plant," everybody started hollering. It is still the same, even when we clean up the odors.

I had one of the state health department men come down and we spent the whole day with one lady. She said she was getting an odor and she lived to the east of the treatment plant. The prevailing wind was from the west. Unfortunately for us there was a sewer manhole at her back property line and she got an odor from it. She kept us up all night, telephoning the officials at all hours. We went to the houses on both sides of her, where there were children, and yet they never complained. We went over the entire neighborhood and no one had smelled any odors. However, this lady has complained steadily for most of the past three years and every week there would be a call that she smelled odors.

There were odors in one part of town but that has been remedied now. The least little thing that happens, however, and right away it is the treatment plant where the odors come from. This has been a very difficult and annoying problem to correct. At present we are going out and informing the people and even asking them to come to the treatment plant. I think we are gradually getting away from the odor problem.

E. J. Beatty, Engineer Manager, Urbana-Champaign Sanitary District, Urbana, Ill.:—We have a girl scout day camp within only 300 ft. of the treatment plant units, since it is located on the plant grounds. We encourage people to come to the plant and we have a visitor's book to be signed. As soon as the plant was constructed, about 25,000 small evergreen trees were planted and paths and roads were laid out to make the grounds look as attractive as possible. It was realized that you might not get odors 98 or 99 per cent of the time, but that 2 per cent of the time you might get some and that actually a sewage treatment plant in the minds of most people is a nuisance.

We have gone through the cycle of odor control which a treatment plant has to go through. We have tried every possible means and have had some success. We, of course, have good chlorination all the time and have used various chemicals. Recently, good success has been obtained with several of the newer chemicals, but I think the most important part of the whole program is to make the plant attractive and to get away from the

idea that a sewage treatment plant invariably produces an odor.

H. P. Orland, Associate Editor, "Water and Sewage Works," *Champaign, Ill.*:—I have just one little item that I thought might be of interest to some of you. Jack Beatty has taken the odor problem which is a psychological factor and he has translated it into a beautiful piece of public relations. He not only has the girl scout camp, but he has an attractive park area between the main road and his plant property. He is capitalizing on the park area at the moment to educate the junior high school and senior high school boys in the community by extending an invitation to the local Boy Scout council to have a camparee on the plant grounds. There will be somewhere in the neighborhood of 600 or 700 boys camped there. I don't know what he is going to do with all those slit trenches they are going to make, but he will have a lot of kids on that property who will know that the sewage treatment plant is not the stinker they now think it is.

Chairman Niles:—The old saying that 90 per cent of the odors come through the eye rather than through the nose is absolutely true. If you can keep your sewage treatment plant looking like a park, you are going to have very, very few complaints, regardless of which way the wind blows, provided you just exercise good housekeeping practices.

A. C. Bryan, Design Engineer, Department of Public Works, Houston, Texas:—I am all for this good housekeeping. I wish we were doing a better job of housekeeping than we are. I am sure we would somewhat reduce our odor level, but not to the point of eliminating odor problems.

I'm in favor of the psychological approach, too, but I recognize that this matter of odors is a relative thing. To some individuals a certain odor is nauseating while to another individual that same odor can be a pleasant thing. To me the odor of sewage is not unpleasant. I make my living with it, and I feel right at home, but the lady across the bayou from our treatment plant doesn't feel the same way. I don't see how all the roses that I spent $300 to plant two years ago and that have now come into full bloom could have any effect. All the beauty that I put around that plant would not eliminate that lady as a complainant and she is a pretty aggressive individual.

This matter of atmospheric pollution abatement becomes more and more of a problem throughout the nation. Sewage treatment plants are in the frontier of the problem, which has been brought into focus by industry. I think that people now are expecting science to do just anything that they decide they want. We may be faced with some tremendous expenditures in this air pollution field for no other reason than the abatement of sewage odors and other odorous compounds in the atmosphere that are present in minute quantities. If we have to go up sewer and reduce odors to zero (and that is almost what must be done) to satisfy that lady who was snarling mad whether the rest of the neighborhood smelled it or not, we are faced with the expenditures of vast sums of money.

I think the matter of just how we are to approach this problem from a scientific basis will need more attention than we are giving it. That may be a local observation by virtue of the fact that in recent years an air pollution control authority has been set up in my county and some of you know the force they have. We never had any complaints of odors until a telephone number for the specific purpose of receiving odor complaints was published, and then the roof fell in. It will cost a lot of money to get props under it.

We haven't gone up sewer yet because of the cost involved, but we are

going to have to study the problem pretty seriously. We are trying to work in collaboration with the air pollution control authority, and we are trying to give some relief with odor masking or counteraction. Where the greases accumulate and you do not have an immediate and instantaneous method of removal you will have an odor problem.

I am using an odor counteractant now at one of the treatment plants. At another of the plants I just mask over with some creosote. However, that is not the answer because these ingredients are very expensive. I hope that the Federation, in their research program, will think seriously of this odor-control matter.

Van P. Enloe, Superintendent, Clayton Sewage Treatment Plant, Atlanta, Ga.:—I realize odor is a very serious problem and the extent of its seriousness is probably related to the value of the properties surrounding the treatment plant. I am unfortunately in a residential area where property values are pretty high and I have a lot of trouble. I would be afraid to publish a telephone number.

Mr. Miller:—We are treating sewage from 100 pumping stations that has had 14 to 16 hr. of detention time before it is received at one of the three treatment plants. We have tried almost everything we know of in the last six years including psychological warfare. In one case we invited some of the leading citizens in the area to a successful buffet supper at one of the treatment plants.

More realistically, we have tried chlorination. We now chlorinate at some 18 points up line, using up to 400 to 500 lb. of chlorine per day. Up-line treatment with us was not an optional thing, it was absolutely essential. I have been on the telephone all day and until 6 and 8 o'clock at night talking to irate citizens so much that I am getting a little tired of it.

Our sewage temperatures run from 86° F. to 90° F. We also have tried the masking chemicals and have not found them too successful. Chlorination will do the job. There is no question about it in our opinion. Up-line treatment basically is rather hazardous in that we must use ton containers of chlorine gas and these are scattered throughout the community Any gas leak would lead to a situation that makes you worry greatly.

More recently we have tried using chlorinated benzine. We obtain pretty satisfactory results if we get the dose up in the range of 4 to 5 p.p.m. At less than this amount we get little or no results. There is apparently a critical point above which you will get good results.

Another thing we have tried is the use of air. We are in extremely flat country with an average elevation only 3 or 4 ft. above sea level. The use of air is completely successful if there are no dips or rises in the sewer line. We tried it in a line about three miles long from which we were getting a horrible effluent. Eight pounds initial pressure against the blower increased in a period of 24 hr. to 22 lb., or beyond the range of the pumps, due to the fact that the air had pocketed in high points air locking the line.

I agree that the question of odor control is a matter on which we must have some research and Federation attention.

We think we have done about all that anybody can suggest we do to control the odor problem. Unfortunately, it is not only the problem of odor itself, which is obviously serious, but it is one of damage to the sewers. We have a system now only about eight years old and I would say that 25 to 35 years of its normal life have been used. Sewer cave-ins have occurred and will continue to occur unless a remedy can be found. We are spending perhaps $30,000 a year on the up-line phases of control of this problem. We do not have it solved,

but we have whipped it at some points. However, it is extremely difficult to control at other points and certainly needs an answer.

Chairman Niles:—Apparently we are not so far removed from this air pollution matter as we thought we were. At one time the Federation Board of Control threw up its hands and said, let us not get mixed up in air pollution, since we are only interested in the treatment of sewage, either the water or solids that are in it. Whether we like it or not it looks like maybe we are going to be involved in air pollution, at least odor pollution; so maybe the officers of the Federation had better take another look at this problem.

W. E. Ross, Superintendent, Richmond (Ind.) Sanitary District:—You think you fellows have a little odor problem. If any of you have gone out in the back yard and lifted the lid off your garbage can, you no doubt had your olfactory membranes slightly offended, but when you concentrate 20 tons of garbage per day in one place, you find that the odor gets a little bit obnoxious. As far as odors around the treatment plant are concerned we had them pretty well knocked out. However, three years ago we started garbage grinding and with that came the attendant odors that follow garbage-collection trucks and also the problem of maggots.

We have always encouraged the taxpayers of the community to come down and find out where their money went. We tell them that in sewage treatment they get more benefits for the price of two packages of cigarettes than they can in any other form of business that we know of. They are very pleased to find that out.

We find that we can get along pretty well with our neighbors, about 90 per cent of whom are occupying a stone orchard better known as a cemetery and they don't object too much to what we do. But the people on the other side are becoming a little more conscious of the garbage grinding and they are quite concerned over what we are trying to do. I think all of us will have to consider this matter of odor nuisance.

I have been interested in the horizontal and vertical employment situation because we have 72 employees in the sanitary district, 13 are at the treatment plant and 6 on sewer maintenance. We find a lot of the odor complaints along the sewer system have been caused by the fact that for the last 50 years everybody has taken for granted that a sewer once built will always maintain its original capacity and will keep right on carrying things away without any attention. Now when a complaint relative to odors is received we go out immediately and check the sewers to find out whether or not there is a stoppage in the line. In most cases we find that we do have either a minor or a major sewer stoppage. When these lines are cleaned out we get rid of a lot of trouble.

It is always encouraging to come to these meetings and learn how many problems other people have, because you go home and feel very happy. I am very much interested in how we can solve these odor problems which are becoming increasingly important.

Mr. Hoot:—I think that what we have been talking about so far has been a matter of focusing attention on normal odors that are around the treatment plants. I think one other thing that we ought to give more attention to is the matter of preventable odors that can occur when plants are first started.

For instance, one summer I visited a large sewage treatment plant where I was told that in the early stages of operation, before the digesters were functioning properly the operator of the plant was virtually ordered to handle the entire sewage flow in the works before he had any feasible place

to put the sludge. The result was a terrible putrefactive odor from the digester which became sour and the surrounding neighborhood was up in arms.

It is interesting to me to note that the condition in the digester got so bad, with so much foaming, that it actually spilled over onto the ground and they had to dig trenches to keep the sludge and foam from spreading.

At another treatment plant I heard almost the same story. Apparently the initial operations of these plants were dictated by city officials rather than by the man in charge of the plant. This particular plant was started just when the heavy canning season got under way. Once again, over the operator's objections, he had to take the entire sewage load. As a result, there was a great amount of sludge put into digesters that was not producing methane. The odor problem was quite acute since the treatment plant was located in a rather preferred residential district.

One of the things that always amazed me in both water and sewage works was that just as soon as a facility is anywhere near completed there is considerable pressure to get the plant into operation. It seems to me that in one of the laws we now have in Pennsylvania, we have a foundation for this urgency to get things in operation sometimes before they should be. As you probably know, if a sewage treatment plant is in operation on January 1, the state will reimburse the community 2 per cent of the capital investment of the plant. A potential hazard exists because it means in many cases trying to get the treatment plant in operation before the digesters are able to receive sludge and, in the early stages, an odor condition is created which will leave a bad impression on the people of the community.

From the Floor:—If the treatment plant has to be in operation the first of the year, the middle of the winter is not the time to start a new plant.

Chairman Niles:—Regardless of operation, getting paid by the state for the operation of a treatment plant is quite an item.

C. H. Young, Division Engineer, State Department of Health, Harrisburg, Pa.:—Pennsylvania, under 1953 legislation, is helping municipalities defray the costs of operating sewage treatment plants required by the State for the control of water pollution. Payments are to be made annually and are based on costs of construction of sewage treatment works, main intercepting sewers and main pump stations in an amount not to exceed 2 per cent of these costs. The legislature appropriated $2,000,000, and approximately $1,000,000 was paid out the first year of operation of this Act. The law requires that the treatment works be completed and placed in operation by December 31 of the year preceding the year in which the payment is made. Consequently, for a municipality to receive a payment, the treatment works and appurtenances must be completed and placed in operation by December 31. As Mr. Hoot has indicated, a number of our municipalities have rushed the completion of the plants so as to qualify for the 2 per cent payment, and in some cases the equipment has not been properly tested nor have the operating personnel been fully selected. This has resulted in some operating difficulties which, in the future, we will endeavor to control.

Annual payments are to be made to municipalities which have acquired and/or constructed sewage treatment works since September 1, 1937, and this has presented problems in securing adequate and proper documentation of costs.

Chairman Niles:—Let us return to the original subject of the organization of the larger treatment plants.

Mr. Enloe:—I had never thought of operation as being in any way either vertical or horizontal. As a matter of fact, it seems to me sometimes a lot of our operation comes up from the grass roots. The fellows down below tell us what we ought to be doing.

We have three shifts in each of the five sewage treatment plants serving Atlanta and we find that we get better control of the operation by rotating the shifts so that the operators will come back on the day shift under the supervision of the superintendent of the plant, and the assistant superintendent and the chemist, at least once every year. Then when he goes on the evening or the midnight shift he will have had additional training and be able to keep up with the new ideas that are introduced from time to time.

We do, of course, have laboratory control of the treatment plants. There is one main laboratory which handles the composite samples taken at each of the other plants. A truck collects the samples and brings them into the laboratory every day, except Saturday and Sunday. We find the sewage flow and the load on the treatment plants drop at least one-third on Saturday and Sunday.

Mr. Larson:—What I have to say does not refer to the subject matter of today's discussion at all. I would like, however, to make a suggestion for a subject which we might take up in this Forum at some future meeting.

Out in Illinois we are getting into a hassle about storm water overflows. This is not strictly operation but it has us sort of trembling in our boots. For the last 25 or 30 years, those of us who live in cities which have combined sewers have not worried too much about storm water overflows. It is something we inherited and we have to live with it. Recently, however, a very damaging decision was handed down by one of the appellate court judges. He apparently knew very little about sewage but still felt qualified to render a decision in which he stated that the governing body (in our case, the sanitary district) was responsible, not only for sewage treatment, but also for all drainage in the area. This is a thing that could have tremendous reverberations, especially in the case of fringe areas.

At present, our storm water overflows are located in relatively unimportant areas. But as they start building new real estate developments farther out, these overflow sewers become a vital part of the development. All right, we extend the overflow. A few years later they start building around the mouth of that overflow and pretty soon we are extending our overflows to the Mississippi River. If we are ordered to take not only normal sewage flows, but also storm flows through the treatment plants, we will be faced with some tremendous expenditures.

Chairman Niles:—That looks as if it has some ominous possibilities. I think that if all of us had to plan on ultimate treatment of our storm flows, we might do more than tremble in our boots. I hope there will be some other judges somewhere along the line who have a little more realistic approach.

HATFIELD AWARDS

Remember the new rules for the Hatfield Awards (THIS JOURNAL, **28**, 1, 118; Jan., 1956). Check with your Member Association Secretary for details.

TIPS AND QUIPS

Operator Certification and Schooling

Short courses for sewage treatment plant personnel are an established fact, while operator certification programs are either nonexistent or voluntary. These were the results revealed by a survey recently conducted among the various state health departments by the Florida Water and Sewage Works Operators Association.

Eleven of the states replying reported no certification program of any kind. Only three compulsory programs were reported, indicating that voluntary programs are the first step in professional recognition.

Short courses are presented on either a one-time state-wide basis or held in various regions throughout a state. Only two states reported holding both types of courses.

Results of the survey may be tabulated as follows:

Certification

Voluntary	Compulsory
14	3
Proposed	None
3	11

Short Courses

State	Regional
11	14
State and Regional	None
2	2

Repairing Broken Concrete

Bonding Compound

Broken or cracked concrete floors, walkways or driveways are reported to be successfully patched when a bonding compound is used first to coat the old surface. Tropical Paint Co., Cleveland 2, Ohio, claims satisfactory results for "Tropical Cement Bond." This product is a liquid brushed on the old concrete surface to bond the new patch to it. The area to be patched must be prepared in the usual manner.

Resurfacing and Patching Compounds

Repairing rutted, rough or broken floors, spalled walls, leaky walls or roofs, or other concrete maintenance jobs can be quickly and effectively done in first class condition, according to the claims of the Stonhard Co., 1306 Spring Garden St., Philadelphia 23, Pa. Products are available for these various maintenance projects together with a staff of trained engineers to aid in the practical phases of the repair work. Stonhard products are also available for use on new construction. An interesting booklet entitled "Over the Rough Spots" is available from the Stonhard Co., and outlines features and applications of the various products available.

Sludge Ash Analysis

The quantitative spectrographic analysis of ash from digested sludge produced at the Tacoma, Wash. sewage treatment plant shows the normal and trace elements of a typical sludge from this area.

Element	Per cent
Silicon, SiO_2	68
Phosphorous, P_2O_5	2
Magnesium, MgO	2.3
Aluminum, Al_2O_3	15.6
Iron, Fe_2O_3	1.8
Calcium, CaO	4.8
Sodium, Na_2O	3
Potassium, K_2O	2.5

Traces of other elements—boron, lead, copper, silver, nickel, cobalt, manganese, strontium, chromium and zinc, averaged .007 per cent. The estimated accuracy of a quantitative spectrographic analysis is approximately 20 per cent.

Reviews and Abstracts*

Pollution Abatement Program at Newport, R. I. By E. R. Cobb and D. F. Coburn. *Jour. Boston Soc. C. E.*, **42**, 3, 217 (July, 1955).

The authors describe the development of a comprehensive sewer system and sewage treatment works to remove pollution from the Narragansett Bay waters which are used for fishing, bathing and recreation as well as for naval operations.

The original sewer system was designed in 1880–1885, primarily to carry domestic sewage, with a small allowance for storm water (equivalent to ¼ in. over the drainage area in 24 hr.). Numerous storm overflows were provided.

Metcalf and Eddy, consulting engineers, Rhode Island State Department of Health and the U. S. Navy have intermittently investigated the problem. As a result of the various studies, the state prohibited gathering of shellfish in certain polluted waters and also classed bathing as hazardous.

In 1948, the city of Newport and the U. S. Navy recommended the elimination of objectionable pollution with certain basic procedures: (a) collection of all sewage into the main sewer system; (b) prevention of sewage overflow from the Washington Square outlet except during storm flows; (c) elimination of the Goat Island outfall; and (d) the collection of all Navy sewage in a central sewer system, with treatment before discharge to the receiving waters.

This report reiterated previous recommendations (1928) and brought them up to date.

The project is now under way and is described in detail, with maps and plans of structures and design data. Primary treatment to remove seattleable solids is provided, followed by chlorination. A single plant serves both the Navy and the city. The sludge is to be handled in separate heated digestion tanks, elutriated and dewatered on a coil-spring vacuum filter.

Langdon Pearse

Microbiology in Petroleum Industry. By John B. Davis and David M. Updegraff. *Bact. Reviews*, **18**, 4, 215 (1954).

A comprehensive review of the microbiology in the petroleum industry with 107 references. Topics of special interest include bacterial corrosion of iron and steel, microbial decomposition of organic drilling fluid additives, deterioration of petroleum products, bacterial desulfurization and denitrogenization of crude oil and petroleum products.

H. Heukelekian

Treatment of Auckland Meat Wastes, Auckland, New Zealand. By R. Hicks. Metropolitan Drainage Board (1954).

This is a report on the treatment of packinghouse wastes without admixture of municipal sewage or with only small volumes. A high degree of treatment is not expected.

Adequate grease removal and screening is required at the source. When the temperature of the raw wastes is expected to be from 75° to 85° F. the anaerobic digestion process is considered advantageous, but is reasonably regarded as a pre-treatment process to reduce the high strength of the wastes. The effluent of such process can be rendered fully stable by a short term activated sludge treatment or by a single stage of low-rate filtration.

Where further treatment is required, single-stage filtration, short period activated sludge or lagooning are suggested.

Under conditions occurring in Manzere Inlet, Manukau Harbor, effluents from this process can be discharged without nuisance or serious contamination of bathing beaches. Where adverse conditions occur, secondary processes as applied to municipal sewage will produce stable effluents, with at least one stage of high-rate filtration following primary sedimentation.

Where activated sludge treatment is installed following high-rate filtration, provision should be made for by-passing normal sludge return to avoid sludge bulking.

Langdon Pearse

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* Please send to Federation headquarters all periodicals, bulletins, special reports, etc., which might be suitable for abstracting in This Journal. Publications of public health departments, stream pollution control agencies, research organizations, and educational institutions are particularly desired. Address such material: Federation of Sewage and Industrial Wastes Assns., 4435 Wisconsin Ave., N.W., Washington 16, D. C.

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WRITE FOR BULLETIN 10169

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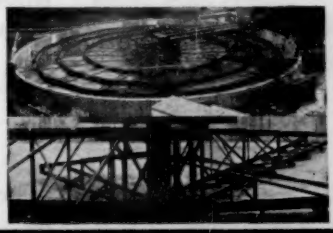

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Proceedings of Member Associations

NEBRASKA SEWAGE AND INDUSTRIAL WASTES ASSOCIATION

The 4th Annual Meeting of the Nebraska Sewage and Industrial Wastes Association was held at the Hotel Yancey, Grand Island, Nebr., on November 3–4, 1955. An interesting program was presented which featured papers on equipment and various treatment plant problems, including public relations.

Officers were elected as follows:

President: W. F. Rapp, Jr., Crete.
Vice-President: V. H. Black, Omaha.
Secretary-Treasurer: V. J. Lechtenberg, Omaha.

V. J. LECHTENBERG,
Secretary-Treasurer

NEW YORK SEWAGE AND INDUSTRIAL WASTES ASSOCIATION

The 28th Annual Meeting of the New York Sewage and Industrial Wastes Association was held at the Belmont Plaza Hotel, New York, N. Y., January 19–20, 1956. A total of 270 members and guests registered for the meeting.

The first morning's technical session led off with the showing of the Cast Iron Pipe Research Association's film entitled, "Water—Wealth or Worry?" After this the following papers were presented:

"Waste Treatment at the Channel Master Corporation, Ellenville, N. Y."

(*Continued on page 157a*)

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by E. J. Quinlan, Chief Engineer, Channel Master Corp., and Dr. Louis Weisberg, Consulting Chemical Engineer of New York City, N. Y.

"Kinetic Studies on the Oxidation of Biological Sludges," by W. W. Eckenfelder, Jr., Assistant Professor, Manhattan College, New York City, N. Y.

The noon luncheon was attended by 165 members and guests. Federation President, George W. Martin, and Executive Secretary, Ralph E. Fuhrman, were present. President Martin spoke on some of the activities of the Federation and presented the Bedell Award to R. C. Sweeny. The guest speaker for the luncheon was Mr. W. O. Hall of the United States Mission to the United Nations whose topic was, "You and the United Nations."

Mr. H. A. Faber, on behalf of the Association, presented the following Memorial Awards:

The Kenneth Allen Award to William E. Dobbins for his paper, "Removal of Radioactivity from Laundry Wastes by Trickling Filters."

The Lewis Van Carpenter Award to D. M. Ditmars and J. R. Scovil for their paper, "The Treatment of Sanitary Sewage and Industrial Waste in Pearl River."

The Charles Agar Award to Dr. A. J. Fischer for his paper, "Increased Income from Inventions."

Other papers presented at the technical sessions included:

"Treatment of Milk Wastes at Arcade, N. Y.," by S. I. Zack of Gannett, Fleming, Corddry and Carpenter, Inc., Harrisburg, Pa.

"Radioactive Detergent-Type Alkylbenzenesulfonate in Activated Sewage Treatment," by Ralph House and B. A. Fries of the California Research Corp., Richmond, Calif.

"The New East Greenbush Sewer District," by R. O. Schindler, As-

(*Continued on page 159a*)

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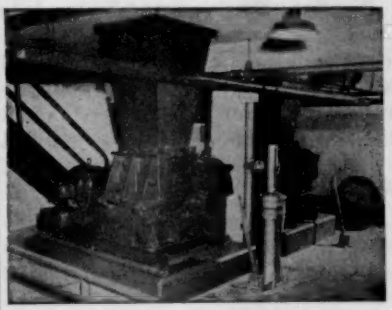

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Two-stage Pumps—Bulletin No. C–1054 describes features of compact two-stage pumps for high head applications.—C. H. Wheeler Manufacturing Co., Economy Pumps Division, 19th and Lehigh, Philadelphia 32, Pa.

Control System—Bulletin 240–M6 describes "plug-in" units for expansion of a central dispatching station controlling remotely located pumps, valves, gates and generators.—Builders-Providence, Inc., 345 Harris Ave., Providence, R. I.

Pipeline Ditcher—A heavy duty pipeline and utility ditcher with tractor-type crawlers has been designed especially for utility work. The ditcher utilizes a hydraulic drive on the soil discharge conveyor, and simplified controls.—Gar Wood Industries, Inc., Wayne, Mich.

Air Classifier—The continuous separation of coarse and fine particles in an airborne mixture from a grinding mill is described in Bulletin AH–467. —Hardinge Co., Inc., 240 Arch St., York, Pa.

Laboratory Apparatus—Issue No. 2 of the *Daigger Apparatus Digest* depicts a wide variety of apparatus and laboratory materials, including timing devices, refrigerating equipment and stirrers.—A. Daigger & Co., Kinzie at Well St., Chicago 10, Ill.

Metal Grating—A 16-page Data and Specification Manual covers all types of steel grating, floor armor, stair treads, vessel liners, decking and drain grates.—Klemp Metal Grating Corp., 6605 S. Melvina Ave., Chicago 38, Ill.

Circular Collectors—Illustrated Bulletin 9W65 presents a complete picture of Walker circular collectors, including tractor drive units and pier and bridge supported mechanisms.—Walker Process Equipment Inc., P. O. Box 266, Aurora, Ill.

Aeration Equipment—Details on diffused air aeration equipment are given in Bulletin 22S61. Equipment applications include activated sludge aeration, aerobic digestion, pre-aeration and others.—Walker Process Equipment Inc., P. O. Box 266, Aurora, Ill.

Filter Felt—A chemical-resistant synthetic filter felt made of Dynel has principal applications in pressure filters and centrifuges.—Filtration Engineers, Inc., 155 Oraton St., Newark 4, N. J.

Adjustable-Speed Drive—Bulletin GEA–6234 details an adjustable-speed drive for electric motors. Printed control circuits are featured.—General Electric Co., Schenectady 5, N. Y.

Vertical Pump Motors—Hollow-shaft, high-thrust type vertical electric motors (7½ to 500 h.p.) are illustrated in the 12-page Bulletin GEA–6280.—General Electric Co., Schenectady 5, N. Y.

Cast Iron Gates—A horizontal flood type valve and cast iron sluice gates are described in new releases.—Snow Gates & Valves, 2437 E. 24th St., Los Angeles, Calif.

Centrifugal Separator — Catalog 112–344 describes numerous applications of centrifugal separators for solids separation and classification of various industrial waste materials. Used to screen objectionable waste material out of waste effluents and for processing sewage sludge.—Southwestern Engineering Co., 4800 S. Sante Fe, Los Angeles 58, Calif.

Instrumentation—Bulletin 1–15 presents a 16-page illustrated coverage of water and waste treatment instrumentation products and installations.—Foxboro Co., Foxboro, Mass.

sistant Sanitary Engineer, New York State Health Department.

"The Design and Construction of a Large Intercepting Sewer," by L. G. Rice, Consulting Engineer, and E. J. Auffant, Westchester County Department of Public Works, White Plains, N. Y.

"Methods of Correcting Storm Water Infiltration in the Sanitary Sewers of Tonawanda," by A. G. Martin and Channell Samson, Town of Tonawanda, and N. L. Nussbaumer, Consulting Engineer, Buffalo, N. Y.

The morning session of the second day was given over to an excellently prepared and presented panel discussion led by Program Chairman, K. S. Watson. The unique discussion simulated a conference between representatives of regulatory agencies and industry regarding the proposed construction of a chemical manufacturing plant which would produce sanitary and chemical wastes.

Appearing as plant management was C. Coakley of the National Aniline Division, Allied Chemical and Dye Corp. W. H. Larkin of the New York State Health Department appeared as the representative of the regulatory agency. Others on the panel were: W. M. Steinfeldt of Eastman Kodak (representing industry's waste specialist's group), John J. Baffa, Consulting Engineer of New York City, N. Y. (as the consulting engineer), Herman Lauman, Contractor, New York City, N. Y. (as the contractor), and T. J. Kenny, Lederle Laboratory Division, American Cyanamid Co. (as the plant operator).

The following officers were elected:

President: J. M. Brown, Jr., Pearl River.
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Treasurer: J. C. Brigham, Albany.
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(Continued through page 165a)

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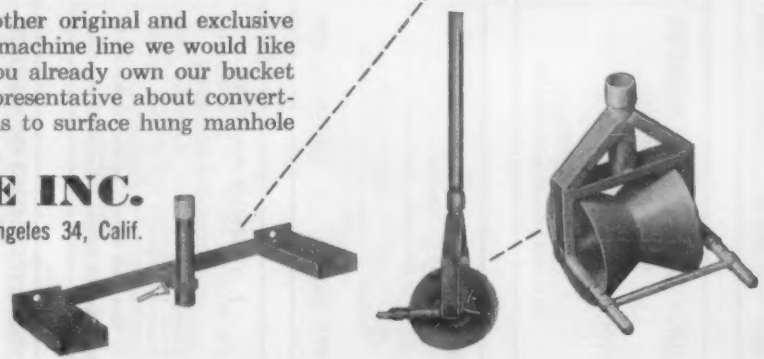

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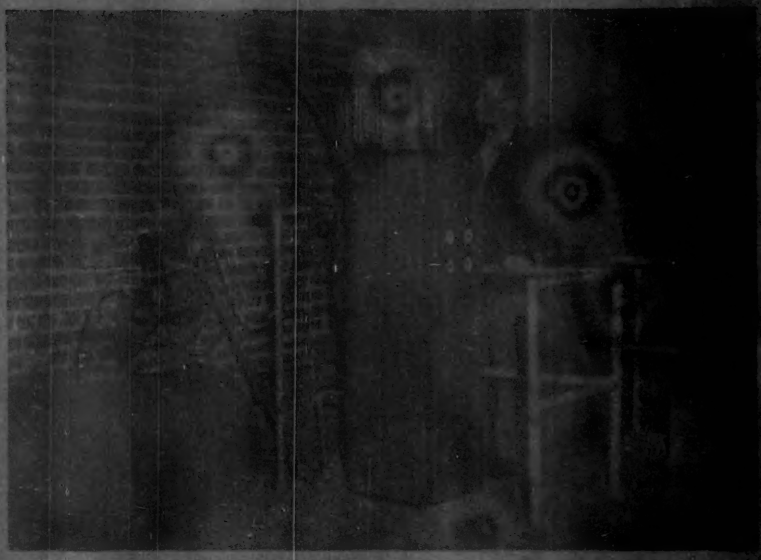

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